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Natural regeneration of native vegetation on abandoned agricultural land in the Fitzgerald Biosphere

Nerilee Boshammer
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Natural Regeneration of Native Vegetation on Abandoned Agricultural Land in the Fitzgerald Biosphere

Nerilee Boshammer



A Thesis submitted in partial fulfillment of the requirements for the award of
Bachelor of Science (Environmental Management) Honours
at the School of Natural Sciences,
Faculty of Computing, Health and Science,
Edith Cowan University, Joondalup.

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Supervisors: Dr Eddie van Etten & Dr Ray Froend

Regeneration at Bob's Bush (*Grevillea pectinata* in foreground)

ABSTRACT

Much of the natural landscape in the south-west of Western Australia has been severely modified as a result of past and current agricultural activity. One of the most conspicuous changes has been the large scale clearing of native vegetation. The evidence of the negative impacts of this vegetation removal on the natural environment is now extensive, particularly in the south-west region of the State.

In order to prevent further degradation of the landscape of the south-west and subsequent loss of endemic species, strategic revegetation within the agricultural landscape is required. Native vegetation corridors can be established, linking areas of remnant vegetation and enhancing ecosystem function and habitat value.

Natural regeneration of old-fields is one method that can assist in the cost-effective development of vegetated corridors. Natural regeneration of old-fields is the process by which agricultural land is abandoned and left to revegetate. It is a form of secondary succession, which involves the replacement of pre-existing vegetation following a disturbance that disrupts that vegetation.

The ecological processes encompassed within the concept of old-field regeneration have been studied extensively in North America, tropical Latin America and parts of Europe. This work has illustrated the ability of native plant communities to recolonise previously disturbed or degraded areas and redevelop self-sustaining ecosystems. It has also shown that regeneration rates vary considerably as a result of different barriers to re-establishment, such as soil condition, availability of viable seed and climatic conditions.

Comparatively few studies of old-field regeneration have been conducted in Australia. A study into ecosystem assembly on old-fields in the West Australian Wheatbelt is currently being undertaken. It will be the first systematic examination of old-field regeneration in Australia and is anticipated to have broad implications for ecosystem restoration. The majority of recent Australian research is targeted at how old-field regeneration can be harnessed to aid biodiversity conservation and ecosystem restoration in agricultural regions.

The aim of this research was to examine the progression of old-field recovery in the Fitzgerald Biosphere Region in the context of time since abandonment and to identify potential constraints. The assessment of the progression of old-field recovery involved contrasting the floristic characteristics of paddock areas with that of adjacent remnant vegetation. In addition, a profile of the soil characteristics and proximity to adjacent remnant vegetation was developed, in order to ascertain potential influences on the progression of old-field recovery.

The results of this study indicated that time since abandonment was the most important constraint on old-field recovery. Proximity to remnant vegetation was also established as having some influence over diversity. Strong correlations existed between the state of a number of soil properties and vegetation composition, particularly compaction, organic matter and nutrient content, however further study is required in order to establish whether or not recovery is being influenced by them. From these results, it is recommended that old-field recovery does present a viable revegetation technique in the Fitzgerald Biosphere, however the potential constraints identified by this research have to be considered during its implementation.

It is anticipated that this study will provide private landowners and landcare organisations with relevant information regarding the capacity of native vegetation to recover on old-fields and consequently, whether it will provide a viable future revegetation option. At the very least, it is anticipated that this research will facilitate more extensive future study into old-field recovery of the unique and biodiverse vegetation of the Fitzgerald Biosphere.

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

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Signed.....

Date.....17/12/04.....

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

1.1.1 Clearing for Agriculture in the south-west of Western Australia

Much of south-western Australia's natural landscape has been severely modified as a result of past and current agricultural activity. One of the most conspicuous changes has been the large scale clearing of native vegetation in the Wheatbelt region of the south-west (Figure 1.1). The evidence of the negative impacts of this vegetation removal on the natural environment is now extensive (Hobbs, 2001). It is predicted that salinity alone, if left unchecked, will claim more than 30% of the south-west land surface. As a result, 450 plant species endemic to the area are at risk of extinction and 75% of the region's waterbird species will decline in numbers, due to loss of freshwater habitat (Gondwana Link, 2003).

Broad-acre agriculture rose to prominence in the south-west in the early 1900s. At the time, Western Australia's economy was in jeopardy, with a steadily declining return from gold mining, a scarcity of jobs and general uncertainty about the future (Beresford, Bekle, Phillips & Mulcock, 2001). The future prosperity of the State was reliant on the ability of its people to develop an alternative export income. The ideal choice was to expand existing wheat production, with its low input costs and rapid returns (Burns, 1976).

Clearing to facilitate the expansion of the wheat industry occurred at a rapid rate. In 1900 only 200,000 acres were under production. By 1930 however, 4.5 million acres had been cleared (Beresford *et al*, 2001). Following the end of World War II, returning soldiers were rewarded with the War Service Land Settlement Scheme (Bignell, 1977). From 1945-1961 the area under cultivation in WA almost doubled to provide for returning soldiers, from 14-25 million acres. Technological advances in machinery, fertiliser and chemical production aided this expansion to more marginal farming areas (Bolton & Hutchison, 1973).

The crash of wheat prices in 1969 spelled the end of the massive land release schemes of the past, although small scale clearing continued into the 1980s. As a consequence of the expansion of the Wheatbelt, 59 million hectares of native vegetation were cleared (Beresford *et al*, 2001).

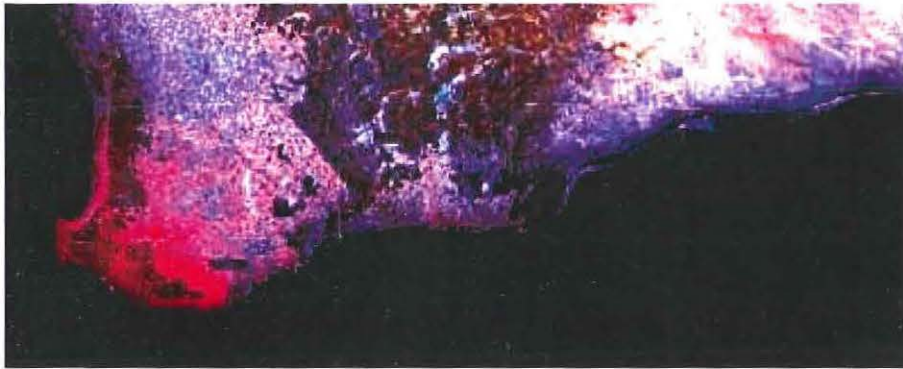


Figure 1.1: Extent of clearing (shown as bright red-pink) in the south-west of Western Australia (Gondwana Link, 2003).

1.1.2 Clearing for Agriculture in the Fitzgerald Biosphere Region

The Fitzgerald Biosphere is an approximately 870, 000 hectare region situated on the south coast of the south-west land division (Figure 1.2). Of this, about 577,000ha has been cleared for agricultural use, predominantly cropping and sheep grazing (Thomas, 1989). The near-pristine native vegetation of Fitzgerald River Natural Park covers 328,026ha of the Biosphere, however Thomas (1989) estimated that only approximately 5% of the surrounding agricultural area was uncleared.

Like much of the Great Southern Region, the farming history within the Biosphere is considerably shorter than that of the northern and eastern regions of the Wheatbelt (Beresford *et al*, 2001). Farming had been occurring in isolated pockets throughout the region since the 1850s, but it wasn't until the War Service Land Settlement schemes of the 1950s and 60s that agriculture in the area really expanded (Thomas, 1989).

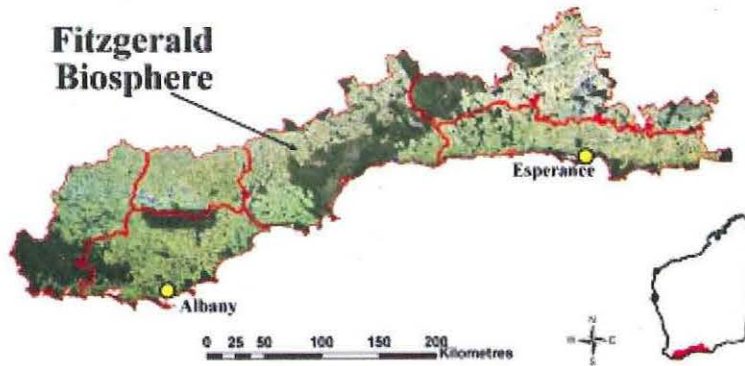


Figure 1.2: Location of the Fitzgerald Biosphere in a state and regional context (South Coast Regional Initiative Planning Team (SCRIPT), 2003).

Despite evidence of landscape deterioration arising from clearing in the Wheatbelt, particularly in the form of salinity, the State Government was pushing for the Great Southern to be opened up for wheat and sheep production (Burns, 1976). Much of the land released under these post-WWII schemes was Conditional Purchase, in that owners were required by law to have 50% of their property under cultivation within the first six years of ownership (Beresford *et al.*, 2001). As a result, clearing within what is now the Biosphere in the 1950s-70s was very efficient and the majority of the 577, 000ha that is now cleared for agriculture was opened up in the space of 20 years (Vaux, 1989).

1.1.3 Landscape Impacts

The impacts of the clearing within the Fitzgerald Biosphere Region have been alarming, particularly wind erosion and dryland salinisation. Salinity mapping and monitoring undertaken in 1998 revealed that an estimated 12% of farmland within the Biosphere is currently affected by salinity (Furby, 1998). This could potentially increase to 25% during the next 15 years, unless appropriate remediation is carried out (Furby, 1998).

Wind erosion has also become a major problem on cleared lands in the Biosphere, particularly those on sandy soils (Edmondson, 1989). During 1960-71 wind erosion and sandblasting was a major concern in the Jerramungup area, with localised events in subsequent years (Goddard, Humphry & Carter, 1981).

The period from 1980-81 saw particularly severe and widespread wind erosion occurring in the Jerramungup, Gairdner River, Jacup and West River areas (Goddard *et al.*, 1981). An estimated 44,000ha were seriously affected by sandblasting and wind erosion in 1980 and over 64, 000ha in 1981 (Goddard *et al.*, 1981). The cause was attributed predominantly to the soil disturbances created by cropping (Goddard *et al.*, 1981). A number of cases were attributed to sheep overgrazing, however no significant relationship was found between whole-farm stocking rates and wind erosion (Goddard *et al.*, 1981).

Remediation of this wind erosion has involved the widespread planting of windbreaks, often with commercially viable species such as *Pinus pinaster* (Runge & van Gool, 1999). Cropping systems based on the principle of minimum soil disturbance, such as no-till sowing and direct drilling and conservative stocking rates on particularly susceptible soils are also being employed (Runge & van Gool, 1999).

1.1.4 Impacts on Terrestrial Biodiversity

The core of the Fitzgerald Biosphere, the Fitzgerald River National Park, is one of the most biodiverse areas in the south-west (Newbey, 1995). The park encompasses approximately 1883 plant species, equating to 23% of the 8000 taxa found in the south-west of Western Australia (Newbey, 1995). Of the species inhabiting the Fitzgerald, more than 250 have high conservation value and 14 are gazetted as rare (Thomas, 1989). In addition, 72 species are endemic to the park, including the Royal Hakea (*Hakea victoriae*) and the Weeping Gum (*Eucalyptus sepulcralis*) (Newbey, 1995).

The avifauna within the park has been recorded at 184 species and the mammalian fauna at 20 species, the highest of any reserve in the south-west (Thomas, 1989). A number of bird species inhabiting the park are rare and endangered, owing predominantly to loss of habitat in surrounding cleared areas (Crib & Henry-Hall, 1988). These include the Western Whipbird, the Brown Bristlebird and the Ground Parrot (Thomas, 1989). Five of the 20 mammal species are rare and endangered for the same reason, including the Tamar Wallaby and the Dibbler.

It is reasonable to assume from the diversity of the Fitzgerald that the surrounding area was also very diverse prior to clearing. This area was protected from clearing as it was gazetted as a national park in 1973, partly in recognition of its diversity and also because it had been established that it was not fit for agriculture (Hall, 1992). The number of rare and endangered flora and fauna inhabiting the park illustrates that the removal of 577,000ha of native vegetation impacted significantly on the flora and fauna of the Biosphere.

Clearing is still impacting on the biota within the Biosphere, albeit indirectly. The native vegetation that was not cleared initially is now highly fragmented. The isolation of remnants, particularly smaller ones, restricts resource and gene flow and reduces species and genetic diversity within remnants (Bridgewater, 1987). This in turn reduces the ability of ecosystems within remnants to tolerate stresses, such as increased salinity and weed invasion (Hobbs, 2001).

In addition, the root pathogen *Phytophthora cinnamomi* is having significant negative impacts on vegetation health throughout the region (Hopper, Harvey, Chappill, Main & Main, 1996). The Proteaceae and Epacridaceae are common to the south coast heathland vegetation and are particularly susceptible to this pathogen, with species such as *Banksia brownii* on the verge of extinction (Hopper *et al.*, 1996).

1.2 CURRENT REVEGETATION OPTIONS AND STRATEGIES

Revegetation of the agricultural landscape in the interests of biodiversity and natural ecosystem function has been occurring throughout the south-west for decades. The approaches to this revegetation have evolved over time to recognise the importance of ecosystem connectivity at the landscape scale, using local species (Bridgewater, 1987). It is now acknowledged that in order to prevent further loss of the unique species of the south-west, strategic revegetation across the agricultural landscape is required that both replenishes depleted habitat and creates links between habitats (Hobbs, 1997). This facilitates the enhanced movement and interaction of genes and individuals across regions, thereby improving the vigour of remaining ecosystems (Hobbs, 1997).

The techniques generally employed to implement revegetation strategies in the south-west are direct seeding and planting of seedlings (Schirmer & Field, 2000). There are advantages and disadvantages associated with both of these techniques and success is often variable, particularly with regard to direct seeding (Schirmer & Field, 2000).

The advantage of direct seeding is that it is less expensive than planting and is quicker and less labour intensive to implement (Dalton, 1993). This is an important consideration for both government and non-government groups with limited resources (Greening Australia, 1995). Direct seeding also encourages rapid and vigorous root development, whereas seedlings generally exhibit greater vegetative (above ground) development, as they are pre-grown in nursery conditions (Hartmann, Kester & Davies, 1997). This lack of root growth in seedlings can lead to mortality and wind damage during unfavourable conditions following planting (Dalton, 1993).

The major advantage of planting is that it is less restricted by climatic and soil conditions than direct seeding (Schirmer & Field, 2000). Successful seeding is highly dependant upon reliable rainfall and particular soil types, for example seeding is not appropriate for heavy clays or unstable sands (Lefroy, Hobbs & Atkins, 1991). Seedlings are preferable when rapid growth of regeneration is required, as they exhibit much faster growth rates in the first years following planting than germinants from direct seeding (Dalton, 1993). Direct seeding success rates are influenced by factors including low seed viability, predation or extreme weather events that inhibit germination, making it a somewhat unreliable method (Schirmer & Field, 2000).

Soil preparation is also required for direct seeding to be successful, particularly ripping, whereas seedlings can often be planted via direct drilling methods, which causes far less soil disturbance (Whisenant, 1999). Weed control is necessary for direct seeding and planting in order to prevent competition, mainly from exotic species. Fencing to prevent herbivory and trampling is also standard, particularly in agricultural areas (Greening Australia, 1995).

These methods of revegetation are valuable and generally very successful when applied to small areas on properties to create shelterbelts etc., however they may not always be appropriate for large-scale revegetation projects (Lefroy *et al.*, 1991). The initial cost associated with these methods is generally high and subsequent costs, particularly involved with weed control, can also be very high and labour intensive (Schirmer & Field, 2000). In order to successfully implement large-scale, coordinated revegetation projects, it may prove more feasible to consider less expensive and labour intensive approaches to supplement these conventional methods. As illustrated in Table 1.1, natural regeneration is potentially a much less expensive method than direct seeding and planting, particularly at the larger scale because of reduced fencing costs (Table 1.1).

Table 1.1: Cost per hectare for a number of revegetation approaches in different environments, according to project area. Adapted from Schirmer & Field (2000).

Project Type	Total costs/ha for 1ha project	Total costs/ha for 10ha project	Total costs/ha for 50ha project
Assisted natural regeneration - warm moist temperate region	\$2255	\$905	\$603
Direct seeding – ex-pasture in warm moist temperate region	\$3223	\$1518	\$1174
Seedlings – semi-arid region	\$2389	\$1486	\$1286
Tubestock – semi-arid region	\$2603	\$1921	\$1704
Seedlings – ex-pasture in warm moist temperate region with contract planting and fertiliser	\$4229	\$2547	\$2166

1.2.1 Natural Regeneration as a Revegetation Option

Natural regeneration of old-fields is one method that can assist in the cost-effective development of vegetated corridors at the regional scale. Natural regeneration of old-fields is the process by which agricultural land is abandoned and left to revegetate independently of human intervention (Whisenant, 1999). It is a form of secondary succession, which involves the replacement of pre-existing vegetation following a disturbance that disrupts that vegetation (Bazzaz, 1979).

Old-field regeneration is a broad term and can often be interpreted simply as vegetation cover, rather than native vegetation replacement. Recovery refers to the re-establishment of

plant species and community structure that characterised the pre-existing vegetation (Bazzaz, 1996). For the purposes of this study, regeneration will be considered in terms of native vegetation recovery.

In Western Australia sustained funding of rehabilitation projects is rarely assured, so economics plays an important role in decision making. During the last ten years, old-field regeneration has been seriously considered as a regional revegetation option in Western Australia because of its cost-effectiveness (Abensperg-Traun, Arnold, Steven, Atkins and Hobbs, 1996), however the majority of this research has been undertaken in the central Wheatbelt, with no documented study specific to the Great Southern Region.

Research was carried out on native regeneration on old-fields near Kellerberrin in the central Wheatbelt because of concerns regarding the cost of implementing direct seeding and planting (Abensperg-Traun *et al.*, 1996). From this research it was found that old-field regeneration could feasibly be a good method of revegetation, however concern did exist about the slow rate of this regeneration and whether or not key plant species were returning (Abensperg-Traun *et al.*, 1996).

Cramer and Hobbs (2003), are currently undertaking a study into ecosystem assembly on old-fields in the West Australian Wheatbelt. It will be the first systematic examination of old-field regeneration in Australia and is anticipated to have broad implications for ecosystem restoration, both in Australia and internationally (Cramer & Hobbs, 2003).

1.2.2 The Gondwana Link Project

Gondwana Link is a cooperative effort between a number of community and non-government organisations, the Wilderness Society, Greening Australia, Australian Bush Heritage Group, Fitzgerald Biosphere Group, Friends of the Fitzgerald and the Mallee Fowl Preservation Group (Wilderness Society, 2004). These partner organisations have brought a range of conservation strategies together, such as public advocacy, revegetation and landcare, land purchase, property covenanting and the provision of incentives for

conservation on private land (Wilderness Society, 2004). The project is funded by government grants and private contributions (Gondwana Link, 2003).

This project was specifically designed to restore ecological connectivity between the woodland areas of the Kalgoorlie Goldfields and the karri/jarrah forests of the Margaret River area (Figure 1.1 & 1.3). Vegetated corridors will be established to link areas of remnant vegetation (Wilderness Society, 2004). Reducing fragmentation of vegetation associations is the most appropriate way to address biodiversity loss and breakdown of ecosystem function as a result of clearing for agriculture (Merriam & Saunders, 1993).



Figure 1.3: The Gondwana Link concept plan for the south-west (Wilderness Society, 2004).

The Gondwana Link project will span almost 1000km (Wilderness Society, 2004). In order to meet the project aims, the revegetation methods employed must be strategic and cost-effective. An alternative approach to revegetation such as old-field recovery would be of significant benefit to this project, if used in conjunction with more traditional methods.

The initial target for revegetation is the area situated between the Fitzgerald River National Park and the Stirling Range National Park. The revegetation of this area will facilitate the reconnection of the two parks via a vegetation corridor. Revegetation in this area is achievable, as existing remnant vegetation is relatively common and there is an availability

of abandoned agricultural land with the potential to be revegetated. Some of this abandoned land has already been purchased and revegetated, including Cherininup Reserve, a 70ha area purchased by the Australian Bush Heritage Fund.

It is anticipated that this research will provide Gondwana Link and other organisations undertaking regional revegetation with valuable insights into the viability of old-field recovery as a revegetation method. Even if the results indicate that old-field recovery may not be an appropriate approach, information about the degree/rate of recovery and the processes potentially limiting or promoting recovery in the area would be valuable.

1.3 SIGNIFICANCE OF THIS STUDY

The ecological processes encompassed within the concept of old-field regeneration have been studied extensively in North America, tropical Latin America and parts of Europe (Bazzaz, 1996). This work has illustrated the ability of native plant communities to recolonise previously disturbed or degraded areas and redevelop self-sustaining ecosystems (Bazzaz, 1979). It has also shown that regeneration rates vary considerably as a result of different barriers to re-establishment, particularly those associated with seed availability and dispersal ability (Bazzaz, 1979).

For example, lack of seed dispersal, seed predation, seedling predation and seasonal drought were all identified as contributing to minimal regeneration of trees on old-fields in Brazil (Nepstad, Uhl & Serrao, 1990). A decline was observed in species richness and abundance of seed rain and soil seed bank in abandoned pasture in Puerto Rico with increasing distance from adjacent undisturbed vegetation (Zimmerman, Pascarella & Aide, 2000). A number of studies explored how old-field regeneration could be harnessed to aid biodiversity conservation and ecosystem restoration, such as that of Aide, Zimmerman, Pascarella, Rivera and Marcano-Vega (2000). This study revealed that although species richness recovered very rapidly on abandoned pasture in Puerto Rico, composition was significantly different to that of the original vegetation. It was suggested that supplementary

planting of original species might be required in addition to old-field regeneration, in order to more closely resemble the native vegetation (Aide *et al.*, 2000).

Comparatively few studies of old-field regeneration conducted in Australia and Western Australia were identified in the literature, with no research specific to the Fitzgerald Biosphere identified. However post-fire regeneration and succession processes are well documented, as fire has a significant influence on Australian native vegetation, either through the inhibition or promotion of regeneration (Specht & Specht, 1999).

It is therefore anticipated that this study will provide agriculturalists and organisations such as Gondwana Link with relevant information regarding the capacity of native vegetation to recover on old-fields and consequently, whether it will provide a viable revegetation option in the future. At the very least, this research is anticipated to facilitate more extensive study into the unique and biodiverse vegetation of the Fitzgerald Biosphere in the future.

1.4 AIMS

1. *To assess the progression of old-field recovery in the Fitzgerald Biosphere by contrasting with the floristic characteristics of remnant vegetation.*
2. *To assess the influences of proximity to remnant vegetation on the progression of old-field recovery.*
3. *To assess the influence of soil properties on the progression of old-field recovery.*
4. *To evaluate the potential for old-field recovery as a revegetation technique.*

1.5 THESIS STRUCTURE

The aim of this thesis was to investigate the progression of native vegetation recovery on abandoned agricultural land in the Fitzgerald Biosphere, to identify potential constraints to recovery and to use the results to evaluate its potential as a revegetation technique. The thesis consists of five chapters.

Chapter 1 has provided an overview of the clearing regime in the south-west as a whole and the Fitzgerald Biosphere and the impacts of that clearing. It introduces the concept of old-field recovery and its potential role in regional revegetation of the agricultural landscape. Chapter 2 provides a more detailed description of the study area and the rationale behind its selection. In addition, the farming history and physical environment of the individual study sites are described.

Chapter 3 addresses two thesis objectives. Firstly, it aims to assess the progression of old-field recovery by contrasting the floristic characteristics of remnant and paddock vegetation and secondly, to assess the influence of proximity to remnant vegetation on the progression of old-field recovery. The aim of Chapter 4 is to assess the influence of the state of different soil properties on the progression of old-field recovery.

Chapter 5 is a synthesis of the results of Chapter 3 and 4. It establishes the major barriers to native vegetation recovery on abandoned farmland in the Fitzgerald Biosphere and from this, evaluates the potential for old-field recovery as a revegetation technique. A number of future recommendations are then made with regard to the management of abandoned areas to attempt to overcome these barriers.

CHAPTER 2: RESEARCH AREA AND STUDY SITES

2.1 INTRODUCTION

This research was based in the Fitzgerald Biosphere and the study sites were located near its western boundary, north of the Pallinup River. They are situated approximately 40km south-west of the rural centre of Jerramungup and 70km north-west of the coastal tourist town of Bremer Bay (Figure 2.1). As no climatic data could be attained for study sites individually, data from the monitoring stations at Jerramungup and Bremer Bay was analysed to establish the climate details for each site. Soil and landform characteristics were also established from information on surrounding areas.

2.1.1 Description of Research Area

As mentioned in Chapter 1, the Biosphere is approximately 870, 000 hectares in area and is situated on the south coast of Western Australia, in the Great Southern Region. It was gazetted in 1978 as part of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) Man and the Biosphere Program, in recognition of the need to protect its floral diversity and to encourage sustainability, particularly in agriculture, to prevent further degradation of the area (Thomas, 1989).

Biosphere reserves are designed to contain a core zone of undisturbed wilderness, with a zone of cooperation surrounding/buffering that core zone (Thomas, 1989). In the case of the Fitzgerald Biosphere, the Fitzgerald River National Park was designated as the core zone and the surrounding agricultural landscape became the zone of cooperation (Figure 2.1). Within the zone of cooperation a variety of activities are encouraged, from recreation to industrial use, as long as they are undertaken in a sustainable manner that does not threaten the natural environment (Thomas, 1989).

Biosphere reserves have three primary objectives. The first is to conserve the diversity and integrity of plant and animal communities within natural ecosystems for the present and the

future and to safeguard the genetic diversity of species. The second involves providing areas for ecological and environmental research, both within and adjacent to Biosphere reserves and the third is to provide facilities for education and training (Specht, 1994b).

The area was first settled by pastoralists in the 1860s, but it wasn't until the 1950's and 60s that the area was widely settled, with the War Service Land Settlement and Conditional Purchase schemes acting as incentives (Bignell, 1977). The region now supports a static rural community of approximately 2000 people, with concentration of population around the towns of Jerramungup, Ravensthorpe, Hopetown and Bremer Bay (Furby, 1998).

Approximately 577,000 hectares of the Biosphere has been cleared for the purposes of sheep grazing and cereal cropping, predominantly barley and wheat (Furby, 1998). Mining for coal and mineral sands occurs in the Ravensthorpe region (Department of Conservation and Land Management, 1991). The Fitzgerald National Park constitutes 328,026ha and provides one of the most important sources of tourism in the area (Department of Conservation and Land Management, 1991). Considerable remnant vegetation cover exists to the north and east of the Fitzgerald, including Lake Magenta Reserve to the north and the vegetation of the Ravensthorpe Range to the east (Figure 2.1). Reserves are also present to the west, including Corackerup, Peniup and Cherininup Reserve (Figure 2.1).

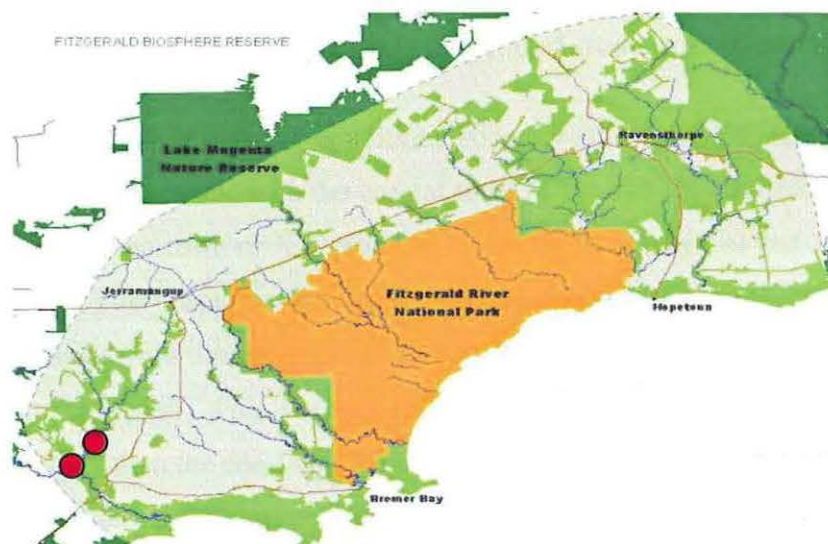


Figure 2.1: Fitzgerald Biosphere, indicating the boundaries of the core zone (orange), remnant vegetation (green) and the zone of cooperation (grey) (Albany Gateway Cooperative, 2000). Approximate location of study sites also indicated in red.

2.1.2 Climate

As is the case for much of the south-west land division, the Fitzgerald Biosphere is subject to a Mediterranean climate, characterised by mild wet winters and hot dry summers (Beard, 1990). However, the Biosphere is much more arid than the west coast, receiving less winter rainfall (Figure 2.2) and experiencing a longer summer.

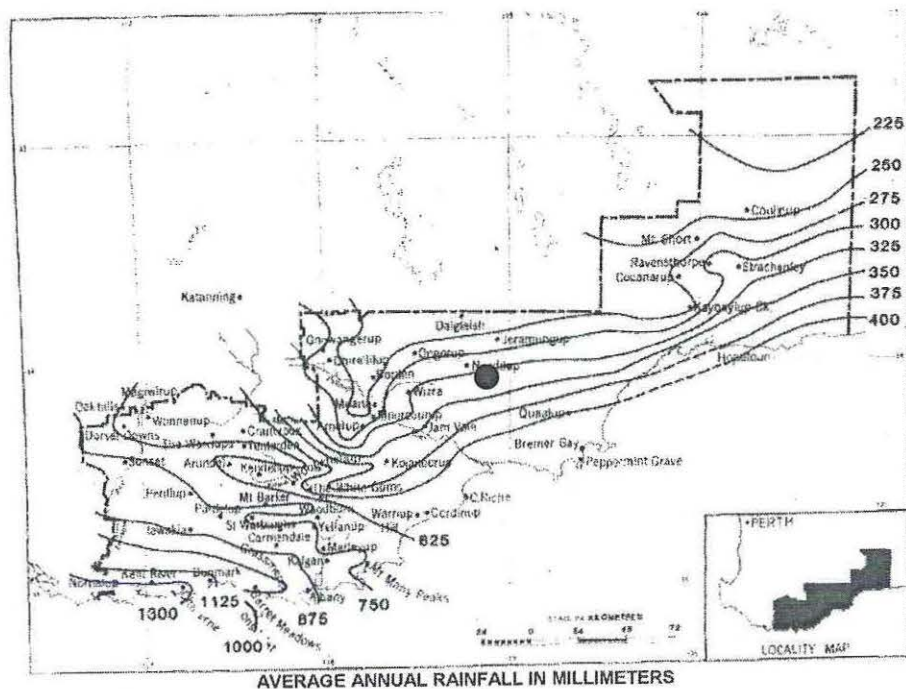


Figure 2.2: Rainfall chart for the south coast region, indicating eastward decrease in average annual rainfall and approximate location of study area (Goddard et al., 1981).

Considerable variation in climatic conditions occurs within the Biosphere. A steep north-south rainfall gradient exists, with the coastal town of Bremer Bay receiving an average of 628mm and the inland town of Jerramungup recording an average of just 392mm (Moir & Newbey, 1995). This disparity in rainfall emerges from higher summer falls in coastal regions, decreasing with distance inland (Beard, 1990). Temperature varies somewhat with distance from the coast, with average summer temperatures 3-4 degrees higher at the northern boundary than the coast and winter averages 1-2 degrees cooler (Moir & Newbey, 1995). Humidity during the summer months is often up to 21% higher at the coast than the northern boundary, but is only marginally higher during the winter months (Moir & Newbey, 1995).

As a result of this climatic variation, the average growing period differs considerably along a north-south gradient, with an 8-month period near Bremer Bay and a 6.5-month period near the northern boundary (Overheu, 2003).

2.1.3 Landforms and Soils

The Fitzgerald Biosphere is part of an ancient, stable and topographically subdued landscape that has undergone gradual, uninterrupted development of soil pattern since the Tertiary-Pleistocene (Johnstone, Lowry & Quilty, 1973).

Much of the Biosphere is underlain by a landscape formed 1400-1600 million years ago, when the Stirling Fault developed parallel to the coast and caused the southern fraction of the Yilgarn Block to subside below sea level (Pilgrim, 1979). The submerged area underwent massive weathering, forming a marine plain (Figure 2.3). As the sea temperature was relatively warm, sponge growth throughout the submerged landscape was prolific. The sponges' hardened frames combined with marine sediment to form spongolite rock (Thomas, 1989).

When the sea level receded and this soft rock was exposed it underwent extensive weathering, as upland river systems cut through the marine plain to the more impervious bedrock in their way to the new coastline (Moir & Newbey, 1995). Spongolite accumulates oxides in its upper surfaces, rendering them relatively resistant to erosion, so weathering was predominantly lateral (Moir & Newbey, 1995). As a result, the marine plain of the Biosphere is characterised by very little relief, interspersed with tall spongolite mesas, breakaways and gorges (Pilgrim, 1979). Regions of particularly resistant granite also appear throughout the marine plain forming jagged peaks of up to 500m above sea level, including the Barren Ranges and the isolated inland peak of Mt Drummond (Beard, 1990).

The northern half of the Biosphere forms part of the Yilgarn Block and is characterised by a gently undulating plain and deeply dissected river valleys (Figure 2.3). This upland region has been undergoing constant weathering for 3,000 million years (Moir & Newbey, 1995).

In addition, extensive laterisation occurred throughout the region during the early Tertiary, more than 25 million years ago (Hopper *et al.*, 1996). Laterite soils are characteristic of the south-west, derived from the deep weathering of granite under climatic conditions reminiscent of present day tropical conditions (Hopper *et al.*, 1996). This deep weathering resulted in the heavy leaching and deposition of clay particles deep in the soil profile and the accumulation of less soluble minerals in the topsoil, particularly aluminium and iron (Hopper *et al.*, 1996). This created a cemented gravel layer (duricrust) at the soil surface. Weathering of this duricrust has resulted in sandy, gravelly surface soils throughout much of the Biosphere region (Hopper *et al.*, 1996).

The Biosphere is dominated by duplex soils, characterised by an A Horizon of shallow to deep sand/sandy loam, often with considerable gravel content, underlain by clay loams to cracking clays. They have weathered *in situ* from granite or sedimentary bedrock derived from granite and from weathering of spongolite (Overheu, 2003). The depth of this duplex profile differs dramatically, with the soil of the uplands ranging from 2-10m deep, while soil of the marine plain is much shallower at only 80-130cm (Moir & Newbey, 1995). The majority of soils in the region are low in nutrients and trace elements, as they are ancient soil profiles and have been highly leached (Hopkins & Griffin, 1984). Those soils exhibiting higher nutrient content are old alluvial deposits or have weathered *in situ* from sporadic dolerite or greenstone intrusions (Figure 2.3).

This general description belies the complexity and subtle variation in the mosaic of soil types within the region. As in many of the sandplain regions of the south-west, the soils often comprise complex patterns that are not easily observed from examination of the surface soils or topography (Hopkins & Griffin, 1984).

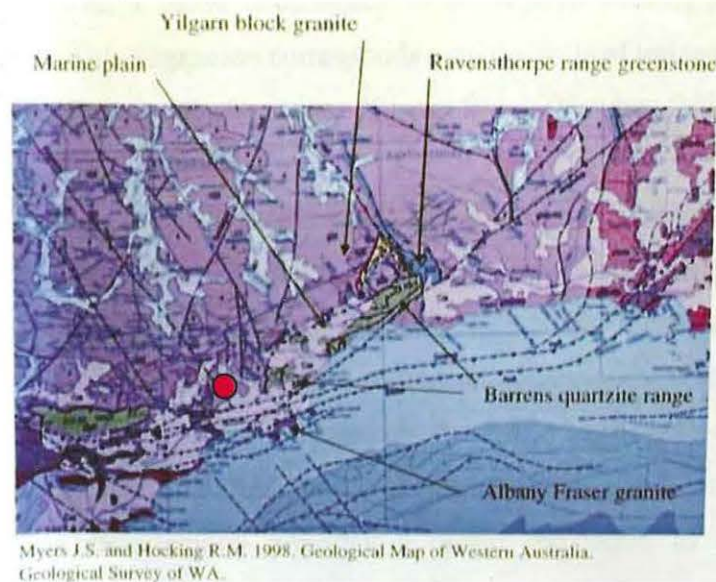


Figure 2.3: Broad regional soil characteristics of the Fitzgerald Biosphere, with approximate location of study area in red. Extract from Myers & Hocking (1998).

2.1.4 Vegetation Characteristics

The vegetation inhabiting the Biosphere is widely recognised as some of the most diverse in the world. This vegetative complexity is directly related to the complexity of the soil mosaic (Hopkins & Griffin, 1984).

As is the case throughout much of the south-west, the native vegetation of the region has been extensively cleared for agriculture (Figure 2.1). However, the clearing regime within the Biosphere was not so intense as that of the central and western Wheatbelt. The marginal nature of the soil prevented agricultural settlement prior to the development of effective inorganic fertiliser, particularly superphosphate (Beard, 1990). Even with this innovation, farmers quickly discovered that the unstable, sandy soils of the region were not conducive to agriculture (Goddard *et al.*, 1981). In addition, the Fitzgerald River National Park was gazetted in 1973, ensuring the protection of almost 330,000ha (Thomas, 1989).

The Biosphere falls within two broad vegetation zones, as described in Beard (1990). The Mallee Region occupies the northern region of the Biosphere, to the north of Jerramungup and Ravensthorpe (Figure 2.4). It is characterised by mallee overstorey, most consistently

opportunity to assess old-field recovery as a future revegetation tool in the region, by examining the progression old-field succession and identifying constraints to recovery.

The motivation behind the focus of this research on the western boundary of the Biosphere was that the first phase of the Gondwana Link corridor revegetation project is being implemented in this area (Figure 2.5). As mentioned in Chapter 1, the initial revegetation phase is currently being carried out in this area because of the availability of remnant vegetation, protected reserves and abandoned agricultural land, improving the feasibility of creating a major regional vegetation corridor between the Stirling Range and the Fitzgerald River National Parks.

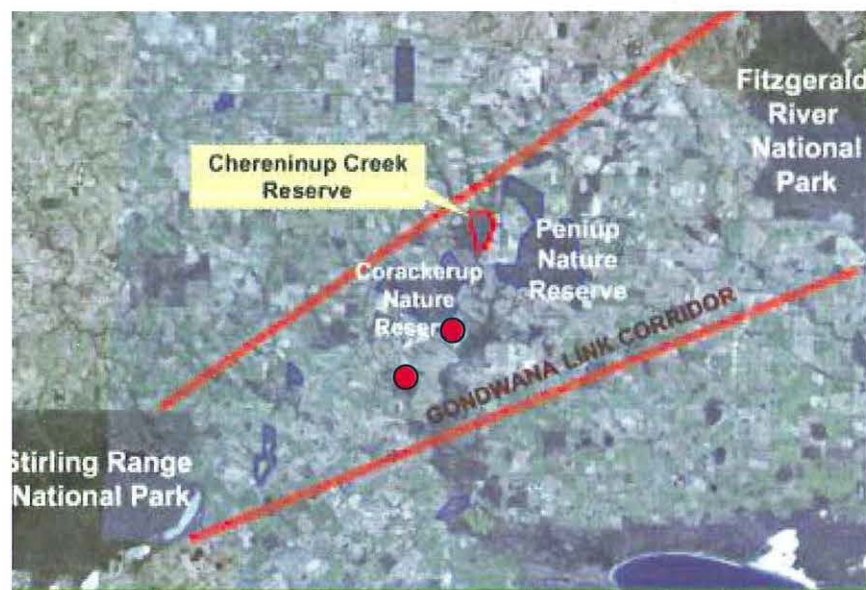


Figure 2.5: Location of study sites in the context of the Gondwana Link corridor revegetation plan (after Cowell, 2004).

The opportunity for this research on old-field regeneration to be of practical use to Gondwana Link was a strong motivation in selection of this study area. In addition, the purchase of agricultural and vegetated land in this area for conservation purposes provided a number of potential study sites (Figure 2.5).

2.3 SELECTION OF STUDY SITES

In order to accurately assess the progression of old-field recovery, the selection of study sites had to be strategic. A number of interest groups having affiliations with the Fitzgerald Biosphere were consulted in order to discover where abandoned farmland existed. Maps and aerial photographs from Gondwana Link and The Wilderness Society were consulted and sites were chosen according to the selection criteria outlined below:

- Three sites of adequate range in age since abandonment, to facilitate the assessment of progression of recovery along an age gradient.
- At least one site of current agricultural activity, to facilitate comparison and analysis of state of soil properties
- Similarity in original vegetation (remnant) and a similarity in soil type, to lend weight to comparative analysis between study sites.
- Similarity in current/past land use and surrounding land use, as the impact of different farming practices/activities on particular soil properties will vary.
- An area of remnant vegetation of considerable size and connectedness adjacent to the area of abandonment.
- The study sites are located in relatively close proximity, to avoid large landscape variation and sampling inefficiency.

Three abandoned study sites and two currently farmed sites were identified that met the selection criteria (description in 2.4 onwards), however the site selection process had three important limitations. The first limitation was that although a number of abandoned properties were available for study, they did not vary greatly in age. As the majority of the Biosphere was cleared during the 1960s and 70s, abandonment has been relatively recent. The oldest available property that met the selection criteria was only 26-30 years old.

Secondly, difficulty was associated with identifying an intermediate-aged property of similar vegetation and soil characteristics to the youngest (abandoned 2003) and oldest (abandoned ~1978) sites. It was discovered that the property abandoned in 2003 contained an area that had been excluded from production prior to abandonment, so this was included

in the analysis. An ideal intermediate age since abandonment would have been about 10 years. However this area was only abandoned three years ago.

The third major limitation was that as the time available to carry out the research was brief, a comprehensive analysis of the progression of old-field recovery in the Fitzgerald Biosphere was not possible. This is a site-specific analysis and an attempt to apply the results and recommendations of this research to other areas of the Biosphere may not be adequate without further study.

2.4 BOB'S BUSH –SITE 1

2.4.1 Site Description

This precise time of abandonment of this property is uncertain, but is believed to be 26-30 years ago and as such, was selected to represent the far end of the old-field age gradient. It is located on eastern side of Monjebub Road, 5km north of the Bremer Bay-Borden Road intersection. It was referred to as Wilkie's Block by those farming in the area when it was first cleared. It is now referred to as Bob's Bush after its current owner, Bob Kozyrski.

The terrain is gently undulating, with a number of dolerite knolls protruding from the landscape. Mallee heath was the predominant vegetation on the sandy duplex soils of the property prior to clearing, as reflected in the remnant vegetation composition. Common overstorey species include *Eucalyptus floctoniae*, *E. conglobata*, *E. thamnoides* and *E. foecunda*, while the understorey is dominated by *Melaleuca* species. Moort (*E. platypus*) and Mallee woodland dominates the lower lying areas and the heavier duplex and clay soils. Vegetation relatively undisturbed by human activity covers 7-800ha, while a third of the property has been cleared for agriculture (K. Bradby, *pers. comm.*, April, 2004).

2.4.2 Farming History and Abandonment

Bob's Bush has a very short farming history. A third of the property was cleared and ploughed for agriculture in 1970 by Peter Wilkie, but was only farmed for a brief period,

estimated to be less than two years (I Macmillan, *pers. comm.*, September, 2004). Stock grazing was not possible on the property, due to a proliferation of *Gastrolobium parvifolium* (Box Poison) following clearing. This species is a member of the genus containing the toxin monofluoroacetate, used in the production of 1080 poison for fox baiting. It is lethal to domestic stock if ingested. In 1978 the property was purchased for conservation by Bob Kosyrski (K. Bradby, *pers. comm.*, April, 2004). Since then, it has undergone very little physical disturbance and native vegetation has been allowed to regenerate naturally in the abandoned paddock areas, however the rate appears to be slow. The characterisation and assessment of this regeneration is important to the research, given that it has been occurring for a considerable period.

2.5 COWBOY COUNTRY – SITES 2 AND 3

2.5.1 Site Description

This property is located on Normans Road, adjacent to Corackerup Nature Reserve. The original name of this property was Ediegarrup, however the current owners refer to it as Cowboy Country, as the landscape is reminiscent of that of the Texan plains (K. Bradby, *pers. comm.*, April, 2004). It is characterised by spectacular spongolite breakaways emerging from an otherwise subdued landscape. This landform is common to the marine sandplain areas of the Biosphere, as detailed in 2.1.3. The soils range from sandy duplexes and spongolite duplexes soils on the more elevated areas and at the feet of spongolite breakaways, to heavy clays and sandy clays on the low lying areas. Soils throughout the property were particularly gravelly. The remnant vegetation on the summits of the spongolite breakaways is dominated by mallee heath similar to that at Bob's Bush, with a *Eucalypt* overstorey and an understorey of *Melaleuca*. Moort (*E. platypus*) and *E. recondita* dominated the slopes and feet of the breakaways.

2.5.2 Farming History and Abandonment

The property was first cleared in 1967 (G. Plane, *pers. comm.*, September, 2004). The 2600 acres that were cleared have been cropped and grazed since that time. Geoff and Michelle

Plane took over operation of the property from Geoff's father 19 years ago. They operated on a three-year rotation of sheep grazing on a clover and grass pasture for two years, followed by a year under either a wheat or barley crop. Occasionally oats were grown as additional sheep feed (G. Plane, *pers. comm.*, September, 2004).

COWBOY COUNTRY (3-YEAR-OLD) – SITE 2

Geoff excluded the low-lying area located in the centre of the property from agricultural practice in 2000. He found that there was too much “poison” in the area to allow sheep grazing (G. Plane, *pers. comm.*, September, 2004). The term poison applies to those species containing the toxin monofluroacetate, as described in 2.4.2. The species identified here was also identified as Box Poison (*Gastrolobium parvifolium*), a species common to the southern region of the south-west. Due to the difficulty in finding a suitable intermediate aged study site, this area was selected once its age since abandonment was established.

COWBOY COUNTRY (1-YEAR-OLD) – SITE 3

Cowboy Country was abandoned in 2003/2004, so it was selected to represent the near end of the old-field age gradient. The National Trust of Australia purchased the property in April 2004 on behalf of Greening Australia. It will now undergo revegetation as part of the Gondwana Link corridor revegetation project (N. McQuoid, *pers. comm.*, June, 2004).

2.6 TORQUATA RIDGE – SITE 4

2.6.1 Site Description

In order to place the results of the soil analysis and observations at Bob's Bush into context, a comparative soil analysis was required for a farm currently in operation. The property selected in accordance with the selection criteria was Torquata Ridge 3009 acre property owned by Ian and Gillian Macmillan. This property is located directly across the road from Bob's Bush, on the western side of Monjebup Road. The geophysical characteristics of Torquata Ridge are very similar to that of Bob's Bush. The remnant vegetation consisted

predominantly of mallee heath, with *E. platypus* becoming common on the lower slopes. The soils graduated from sandy duplexes with a significant gravel fraction in more elevated areas, while the clay fraction increased towards the lower slopes.

2.6.2 Farming History

The property was first cleared for agriculture in 1965 and Ian and Gillian have been on the property since 1966. Generally, they maintain 850-900 acres of the property under barley each year. This is carried out over a three-year rotation, with one year of cropping followed by two years under a clover and grass pasture (I. Macmillan, *pers. comm.*, June, 2004). They run approximately 2300 head of adult sheep and 1000 lambs on that pasture. They practice conservative techniques where possible. They retain stubble and maintain relatively low stocking rates to retain soil structure and to prevent erosion. They have fenced off the creek line running through their property, in order to prevent sheep grazing and to arrest its salinisation (G. Macmillan, *pers. comm.*, June, 2004). Some regeneration is already occurring, however the creek line is becoming increasingly saline.

2.7 EDIEGARRUP – SITE 5

2.7.1 Site Description

When the majority of what is now referred to as Cowboy Country was purchased by the National Trust of Australia, the southern portion was retained for production and the original property name of Ediegarrup was retained (W. Bayly, *pers. comm.*, September, 2004). The entrance to this property is located to the south, off Ongerup-Boxwood Hill Road. Despite its close proximity to the recently abandoned portion, the landscape here was notably different. It lacked the spongolite breakaways of Cowboy Country, boasting instead a gently undulating terrain. The soils were similar, in that they were predominantly sandy duplex, with an increasing clay fraction toward the low-lying areas and increasing gravel content on the upper slopes, however they appeared to be more influenced by the weathering of granite. The vegetation was predominantly mallee heath, with the *Eucalypt* overstorey increasing in height at lower elevation.

2.7.2 Farming History

Robert and Whispie Bayly purchased this area earlier on in 2004. There are currently grazing sheep, however the stocking rate is low as they are still finalizing surveying and other planning issues (W. Bayly, *pers. comm.*, September, 2004). Before it was taken over by Robert and Whispie, the farming history for this area followed that of Cowboy Country.

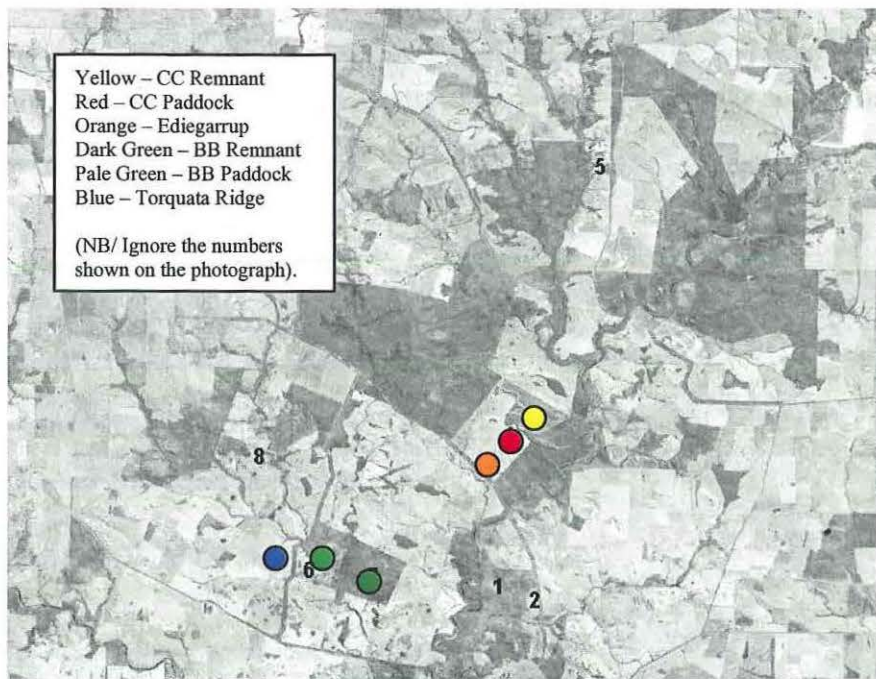


Figure 2.6: Aerial photograph indicating the location of each of the study sites and their proximity to each other (Photo courtesy of Keith Bradby, Gondwana Link).

CHAPTER 3: DESCRIPTION OF FLORISTIC CHARACTERISTICS

3.1 INTRODUCTION

This chapter was designed to meet two main objectives. The first of these was to assess the progression of old-field recovery in the Fitzgerald Biosphere Region by contrasting with the floristic characteristics of remnant vegetation. This assessment was carried out by way of analysis and description of the differences between the vegetation occurring in remnant and paddock areas, both between and within study sites.

The second objective of the chapter was to assess the influences of proximity to remnant vegetation on the progression of old-field recovery. The trends observed in paddock vegetation composition with proximity to remnant vegetation were described and analysed, both between and within study sites. The influence of remnant vegetation on recovering paddock vegetation was an important consideration in this research.

3.2 METHODS

3.2.1 Sampling Design

Gradsect Sampling

A number of factors needed to be considered when undertaking sampling design to ensure adequate data was collected. Representative sampling based on environmental stratification was required. A compromise was also required between statistical sampling, logistical problems and time/costs. In the interests of obtaining statistical power, replicated sampling was important. Gradsect sampling was identified as a form of survey that addressed these criteria specifically (Austin & Heyligers, 1989). In addition to the above criteria, this research required a sampling approach that would facilitate the adequate description of a range of plant communities, both common and uncommon. It also required sufficient

representation of vegetation change over spatial gradients. The gradsect sampling (gradient-directed transect sampling) technique met these criteria (Austin & Heyligers, 1989).

The concept of gradsect sampling was proposed by A.N. Gillison in 1985 (Gillison & Brewer, 1985). It is intended to provide a description of the full range of the floristic variation of a region, via deliberate selection of the steepest environmental gradient present (Austin & Heyligers, 1989). In addition, study sites are selected that are accessible via a road network, in order to reduce survey costs (Austin & Heyligers, 1991). Gillison and Brewer (1985) demonstrated statistically that gradsects are capable of capturing more information about vegetation attributes than randomly placed transects of similar length.

Gradsects are deliberately selected to contain the strongest environmental gradients present in an area in order to optimize the amount of information gained in proportion to the time and effort spent (Gillison & Brewer, 1985). This selection is based primarily upon a visual assessment of vegetation characteristics. In the case of this research, the strongest gradient existed across the zone of transition between remnant and old-field vegetation.

Sampling bias and subjectivity are associated with this method, as gradsect location is selected deliberately on the basis of an individual's assessment of what constitutes a steep environmental gradient (Austin & Heyligers, 1991). However, the sampling design for this research ensured random sampling occurred along each transect, as described below.

Sampling Methods

In order to establish the appropriate number and placement of gradsects a visual assessment of each study site was undertaken by way of aerial photographs and site assessment, bearing in mind the principles of gradsect sampling. The essential criterion of this sampling design was that each gradsect would sample remnant vegetation, paddock vegetation and the zone of transition between them, in order to capture maximum variation in vegetation. Therefore, each gradsect originated within a remnant area and ended in a paddock area, facilitating the sampling of vegetation and soils along the cross section (Figure 3.1).

Remnant size, connectivity and health were important considerations when selecting gradsect location. For the purposes of this research degraded remnants would not provide an accurate illustration of the original native vegetation. Where possible, remnants were selected that were at least 100ha in size or that were connected to other remnant vegetation of more than 100ha. Site inspection and consultation of aerial photography aided in the selection of remnant vegetation that met these criteria. Unavoidably, one of the gradsects at Cowboy Country originated from a remnant that was less than 100ha in size and was isolated from other remnants (Figure 3.1). Site inspection revealed that despite its isolation and small size, this remnant was in very good health and so sampling proceeded.

Following a visual assessment of vegetation characteristics, three gradsects were laid down at each study site in areas where maximum variation was expected, in holding with the gradsect method (Figure 3.1). However the three-year-old Cowboy Country site was only sampled along a single gradsect (Figure 3.1). As it was a small area in comparison to the other study sites, multiple gradsects would have introduced issues associated with pseudo-replication (Dytham, 2003). In addition, the remnant vegetation surrounding it was well sampled for the one-year-old Cowboy Country site, providing a basis for comparison.

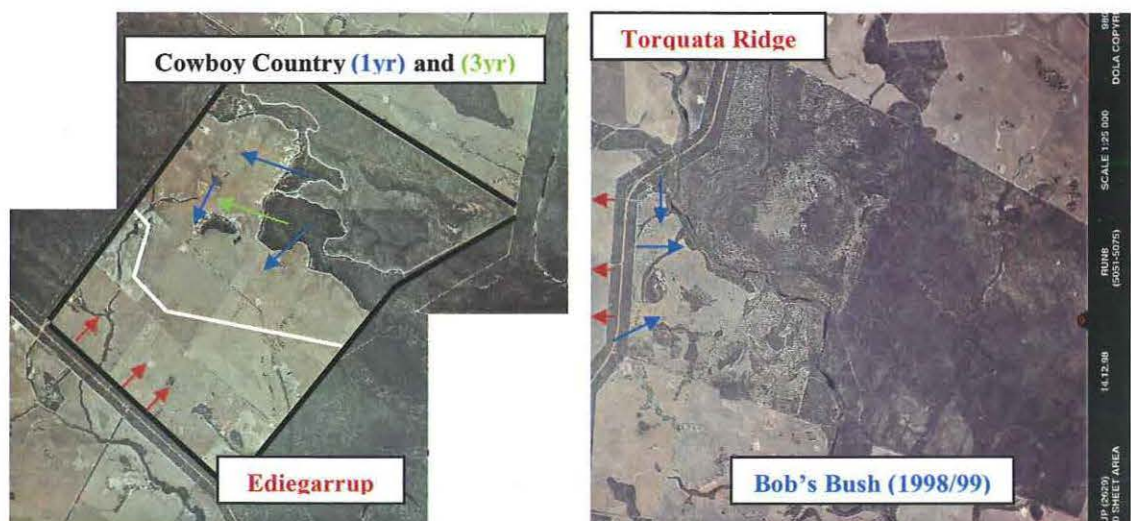


Figure 3.1: Aerial photographs illustrating gradsect arrangement at each study site (Arrows not to scale) (Photographs courtesy of Simon Judd and Jack Mercer, 2004).

The gradsects at the three study sites representing abandoned properties varied in length between 200-300m and consisted of 8-10 sample points. However gradsects in the study sites representing currently farmed areas were only approximately 70m long and contained 3 sample points. Fewer data collection points were required to represent the vegetation and soils of the currently farmed sites than abandoned sites because less variation was expected and they were designed as supplementary sampling points only.

The location of sample points along each transect was based on a visual assessment of expected variation in vegetation characteristics, in holding with the gradsect method. It was important that a minimum of three sample points were situated in the paddock within the first 100m from the remnant edge (Figure 3.2). This area represented the zone of transition and considerable variation in vegetation was expected there. A minimum of two sample points was required in each remnant area, in order to gain an adequate representation of the native vegetation occurring at each site on which to base comparisons with paddock areas (Figure 3.2). Sample points were numbered from 1 onwards as the distance from the remnant area increased (Figure 3.2).

Each gradsect was designed to contain a similar number of sample points, however the arrangement fluctuated in order to capture variability in vegetation patterns within the paddock areas at each study site. For example, a visual assessment of paddock vegetation at the one-year-old Cowboy Country revealed low variability. At Bob's Bush and the three-year-old Cowboy Country site however, considerable variation in vegetation pattern was observed in the old-field areas. Therefore the number of sample points in the old-fields varied from four to eight to facilitate adequate, yet efficient sampling.

Each sample point consisted of three 5x5m quadrats, 20m apart (Figure 3.2). This formed the random component of the sampling design. For within site analysis, each quadrat was treated as an independent data unit, so average values and standard errors could be established for each sample point along each gradsect. These sample point averages were used for the data analysis. Floristic characteristics were measured within the 5x5m quadrat boundary, however three nested 1m² quadrats were used to measure abundance and cover of small plant species.

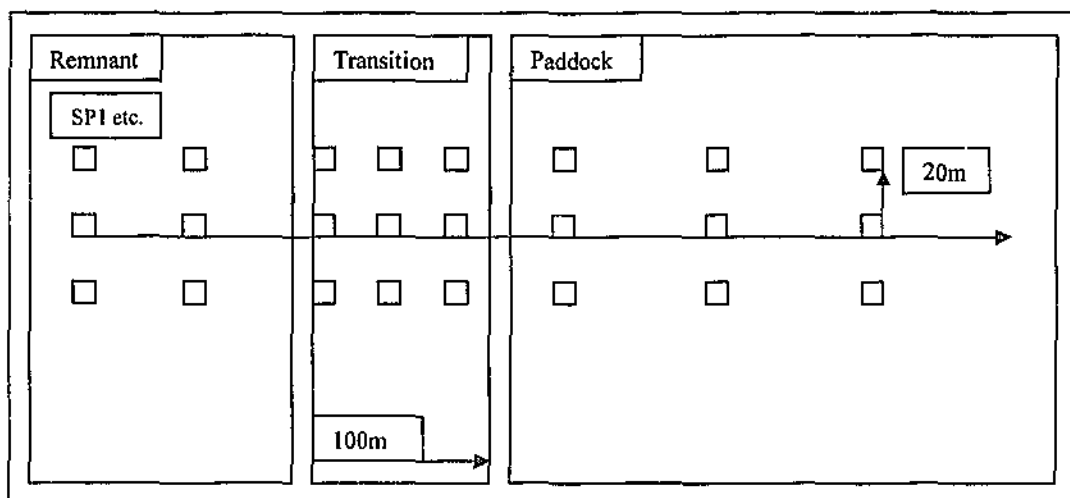


Figure 3.2: Basic sampling design along a single gradsect.

3.2.2 Field Methods

Proximity to Remnant

The distance along each gradsect from the edge of a remnant to the closest edge of a quadrat was measured to represent its proximity to an area of remnant vegetation. This was repeated for the three quadrats at each sample point.

Specimen Collection and Identification

The plant species observed within each quadrat were identified in the field where possible, with the aid of field identification guides. However the vast majority could not be identified in the field. In this instance, a specimen was collected, including a sample of any fruiting bodies or flowers available, placed in a field herbarium and pressed for later identification. A collecting permit was acquired from the Department of Conservation and Land Management (DCLM) prior to any specimen collection.

Species identification was undertaken using key guides, the state herbarium database (FloraBase) and consultation with botanists familiar with the area. As a consequence of sampling during autumn and early winter, only a small proportion of the species observed

were flowering, making positive identification difficult. In order to identify a large proportion of the specimens collected and confirm the accuracy of those identified, botanists from Edith Cowan University and Greening Australia were consulted.

Species Richness, Cover and Abundance

Species richness was calculated by counting the number of species observed within each quadrat. The abundance of each species observed within quadrats was counted. For smaller sized plants, abundance was measured within nested 1m² quadrats and extrapolated to 25m². Cover was measured as a percentage of the quadrat area that each species covered. Again, the cover of smaller species was calculated using nested 1m² quadrats and extrapolated to 25m².

Description of Vegetation Structure

The structure of the vegetation observed within each quadrat was established from an analysis of strata (vegetation layers). The characteristics of the strata were important to the qualitative analysis of the complexity and maturity of vegetation observed at each study site. Within each quadrat, the number, type (by height) and cover of each stratum was determined.

Strata types were divided into tree, tall shrub, shrub and understorey. Those species classified as trees were greater than 2m in height and were characterised by a distinctive main stem. Those classified as tall shrubs were approximately 2m in height and were multi-stemmed. Shrubs were approximately 1m in height and were also multi-stemmed. The understorey class was characterised by herbaceous species, grasses, rushes and low growing shrubs that did not exceed 0.5m in height. The similarities between these strata classes and Raunkiaer life-form classification are described in Table 3.1.

Raunkiaer Life-form Classification

In addition to a taxonomic classification of species, an analysis of species functional characteristics was considered valuable. Raunkiaer life-form classification criteria were

used here to establish the adaptive capabilities of the species identified to variation in environmental conditions, using the system first established by Raunkiaer (1934). This system classifies plants according to the position of their perennating buds, from which growth occurs following unfavourable conditions (Raunkiaer, 1934). The five basic Raunkiaer groups are the Phanerophytes, Chamaephytes, Hemicryptophytes, Cryptophytes and Therophytes (Raunkiaer, 1934). These groups are further subdivided to form more specific classification criteria.

This system is subject to interpretation and the literature varies in its representation of life-form classes. The system adopted in this research was adapted from Specht & Specht, (1999), as it provided a concise breakdown of each of the main groups. Species were first classified in the field according to Table 3.1. The field classification was revisited following species identification to ensure its accuracy. As displayed in Table 3.1, the classification only includes the classes that were observed.

Table 3.1: Raunkiaer life-form classes, with parallels drawn between strata classes. Modified from Specht & Specht (1999).

Class	Sub-class	Symbol	Description
Phanerophyte			Perennating buds/shoot apices born on aerial shoots.
	Microphanerophyte	M	2-8m in height (Strata class: Tree)
	Nanophanerophyte	N	0.25-2m in height (Strata Class: Shrub-Tall Shrub)
Chamaephyte		Ch	Perennating buds born (<25cm) close to the ground (Strata Class: Understorey).
Hemicryptophyte		Hm	Perennating buds located at ground level; above ground parts die back in unfavourable conditions (Strata Class: Understorey).
Geophyte		G	Perennating buds persist below ground during unfavourable conditions, as bulb, tuber or rhizome (Strata Class: Understorey).
Therophyte		Th	Annual/ephemeral species that complete their life cycle from seed to seed during favourable a season (Strata Class: Understorey).
Climber		C	Climbing Phanerophytes that require other plants for support (Strata Class: Shrub-Tall Shrub).
Parasite		P	Extract organic matter and nutrients from stems or roots of host plant (Strata Class: Shrub-Tall Shrub).

Soil Seed Store

Soil samples were taken for germination trials to determine the potential for regeneration from the soil seed bank. Only one transect at each study site was sampled, due to time

constraints. Along that transect, one soil sample was taken from each quadrat. Each sample was taken with a soil corer of 10cm in depth and 5cm in diameter, to ensure a sample of set volume and depth. It was designed to encompass the O and A horizons, as the majority of seed was expected to be stored within the surface soils (Kunzee & Wijdeven, 2000).

The soil samples taken in the field were spread out in individual trays on a bed of sterilised river sand and pyrite, which provided a sterile and well-draining, yet moisture retentive substrate. The trays were placed in a greenhouse of relatively constant temperature and humidity and received water every day for a period of 2 minutes. No other treatment was applied, as the aim was to observe the amount of readily germinable seed within each soil sample, or seed that did not require any specialised conditions in order to germinate. Trays were left for a period of 7 weeks, as this was deemed adequate for germination to occur.

The number of individual germinants observed was recorded on a weekly basis. No distinction was made between species and species identification was difficult, as the germinants were very small. At the end of the seven weeks, the proportions of native and exotic species within each sample were calculated and where possible, species were identified. This analysis was designed to provide an indication of the potential regeneration at each site and the species that may dominate future regeneration.

3.2.3 Data Analysis

Shannon-Weaver Diversity Index

The Shannon-Weaver diversity index was employed to provide an indication of species diversity (Fowler, Cohen and Jarvis, 1998) within remnant and paddock areas at each study site.

The following formula was used to calculate diversity:

$$H = - \sum_{i=1}^s p \log_e p$$

Where: H = value of Shannon-Weaver Diversity Index
 p = proportion of total species cover of quadrat
 $\log_e p$ = natural logarithm of p
 s = number of species in the community

Diversity values were calculated using individual species cover measurements. Cover was considered more appropriate for this analysis than abundance, as cover values provide more equal comparison of dominance of different sized plant species (Kent & Coker, 1992).

Native and Exotic Species

A common indicator of the health of plant communities and the degree to which disturbed communities are recovering is the presence of introduced plant species (Society of Ecological Restoration Science & Policy Working Group, 2002). With this in mind, the species richness of exotic and native plants within remnant and old-field vegetation was compared following species identification.

Annual and Perennial Species

The survival strategies of dominant species in a plant community can often provide an indication as to the stage of succession of that community following disturbance (Bazzaz, 1996). The predominance of annual species is often indicative of a highly disturbed environment, whereas one dominated by perennial species generally indicates a more stable environment (Grime, 1979). With this in mind, a comparison of the species richness of annual and perennial species between remnant and old-field areas was undertaken following species identification.

Annuals were interpreted as being those plants surviving one growing season only, reproducing within that one season. Perennials were interpreted as being those species that survive more than one growing season, be it as underground parts in the case of geophytes or rhizomes or as above ground parts.

Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) in SPSS was employed to analyse the variation in mean values of specific floristic characteristics. One-way ANOVAs of single variables were carried out in SPSS, comparing within site means, as well as differences between remnant and paddock means between study sites.

Within site comparisons were made by sample point, which is a mean value of the three quadrat values at each sample point (Figure 3.2). The majority of between site remnant and paddock comparisons were also established by sample point, however mean remnant and paddock gradsect richness was established by gradsect. Consequently, degrees of freedom/replication included in the analysis within and between sites were generally the same. Mean values were compared for species richness, Shannon-Weaver diversity, native and exotic species richness, annual and perennial species richness and number and type of strata.

ANOVA makes certain assumptions about the data it is applied to, namely that observations are independent both within and between samples, data are normally distributed and that homogeneity of variance exists (Fowler *et al.*, 1998). In a number of cases the data for particular floristic characteristics did not display homogeneity of variance. In these cases the results were treated with caution and a post-hoc test was used that did not assume equal variance when differentiating between means, in the form of a Games-Howell test (Dytham, 2003). The Tukey's-b post-hoc test was used to differentiate between means that expressed homogeneity of variance, as it was a less conservative method of establishing significant differences between samples (Fowler *et al.*, 1998).

Ordination

Ordination was used for data exploration and pattern analysis associated with vegetation composition. Cover values were used for species composition analysis, as they provided a more even spread of values than abundance values. The data was then square-root transformed to further reduce the scale (from 0-100 to 0-10), to prevent species with high cover values such as *Austrodanthonia sp.1* from dominating the pattern analysis.

A similarity matrix was developed between samples and vegetation composition within each study site individually and as a comparison across all five sites, using collated data from each quadrat in the remnant and old-field areas. The Bray-Curtis measure was used to construct the similarity matrix. Multi-Dimensional Scaling (MDS) was then employed to create a spatial representation of the species composition at each site with low dimensionality (2D) (Kruskal & Wish, 1978).

ANOSIM (Analysis of Similarity)

ANOSIM (Analysis of Similarity) was used to analyse the similarity of vegetation composition between remnant and old-field areas across the five study sites. ANOSIM is designed to consider the similarity of sites by analysing multiple variables simultaneously (Dytham, 2003). In this case, the multiple variables were cover of various species.

3.3 RESULTS

It should be noted here that all bars shown in the graphs throughout the results represent \pm SE. It should also be noted here that a letter code was applied consistently throughout the results to represent remnant and paddock areas within each study site in Figures as follows:

BB = Bob's Bush (26-year-old)

CC3Y = Cowboy Country (3-year-old)

CC = Cowboy Country (1-year-old)

TQ = Torquata Ridge (currently farmed)

ED = Ediegarrup (currently farmed)

R = Remnant

P = Paddock/old-field

3.3.1 Species Diversity

The diversity of plant species as represented by species richness and the Shannon-Weaver Diversity Index revealed a number of differences between and within the five study sites. No significant difference in mean gradsect species richness existed between the remnant and old-field vegetation at Bob's Bush, rather the values for each were similar (Table 3.2). As also indicated in Table 3.2, species richness in the old-fields at Bob's Bush was significantly higher than that of the one-year-old site and the two currently farmed sites. Overall species richness at the one-year-old site differed significantly between the remnants and old-fields, with the remnant vegetation containing more than twice the number of species per gradsect than the old-fields (Table 3.2). The three-year-old site could not be

included in this analysis as it was only represented by a single paddock and remnant value, however the mean old-field value indicated that the difference in species richness between it and Bob's Bush was not likely to be significant (Table 3.2).

Table 3.2: Comparison of species richness within remnant and old-field areas at each study site, by gradsect mean (One-way ANOVA: $F = 6.734$, $P = 0.001$).

STUDY SITE	N	REMNANT	SE (+)	OLD-FIELD	SE (+)
Bob's Bush	3	35.33	4.75	29.67	10.08
Cowboy Country (3-yr-old)	1	15	n/a	23	n/a
Cowboy Country (1-yr-old)	3	31.33	2.96	12.33	4.37
Ediegarrup	3	12	0.577	3.67	0.33
Torquata Ridge	3	4.67	0.33	2.33	1.21

The mean diversity of plant species per quadrat revealed rather different results to mean per gradsect, as represented by species richness and the Shannon-Weaver diversity index (Figure 3.3 & 3.4). The remnant area within Bob's Bush showed the greatest species richness of all the sites (10.5 species per 25m²) and in opposition to the results shown in Table 3.2, a significant difference was revealed between the richness of old-field and adjacent remnant vegetation at that site (Figure 3.3). This disparity, together with a high standard error for old-field richness in Table 3.2, suggests high species variability in Bob's Bush old-field. It may also reflect differences of sampling scale, in that the gradsect mean is highly simplified.

Despite a disparity in old-field mean values between the three abandoned sites of different ages, no significant difference was illustrated (Figure 3.3). Surprisingly, there was also no significant difference noted between the species richness of the old-fields of the abandoned sites and the paddocks currently being farmed (Figure 3.3).

Shannon-weaver diversity in the remnant vegetation was significantly higher than that of the adjacent paddock vegetation at Bob's Bush, Cowboy Country (1yr-old) and Ediegarrup (Figure 3.4). It was also surprisingly low in the Bob's Bush old-fields, with no significant difference in mean diversity between it, the one-year-old site or sites still under cultivation (Figure 3.4). Old-field diversity at the three-year-old Cowboy Country site was significantly higher than at the other four sites (Figure 3.4). Mean species richness and diversity in the old-field at the three-year-old site exceeded that of the remnant, however as

shown by the large standard error for this remnant area, diversity was highly variable within the remnant samples (Figure 3.3 & 3.4).

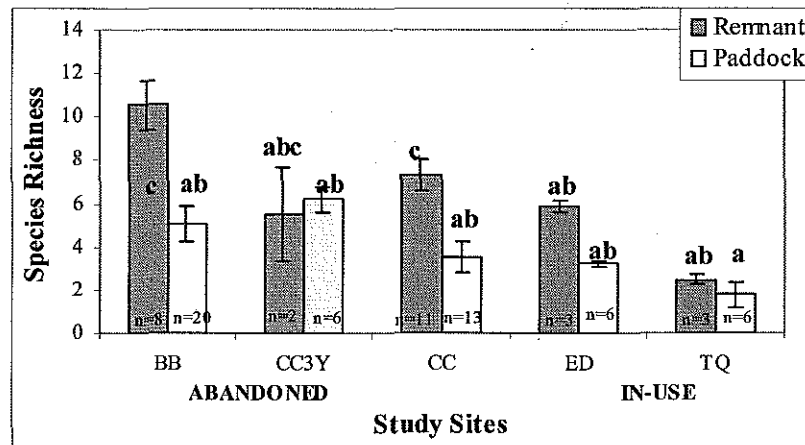


Figure 3.3: Mean species richness per sample point in remnant and paddock areas at each study site ($F = 7.962$, $P = <0.001$). Games-Howell post-hoc test results illustrated by letter code, with means sharing the same letter not significantly different.

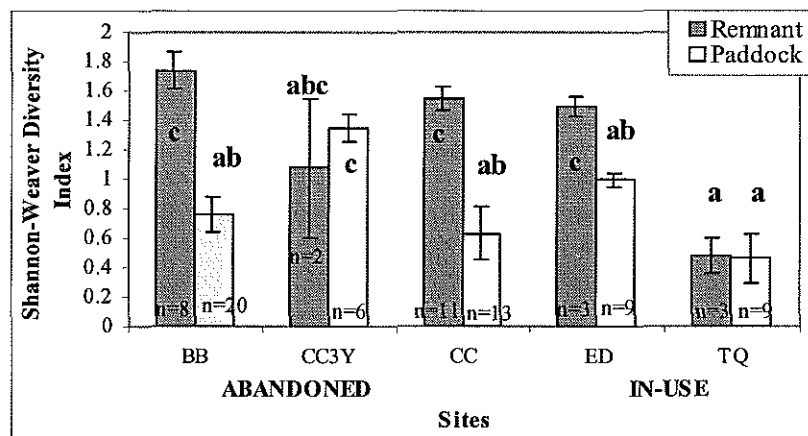


Figure 3.4: Mean diversity (Shannon-weaver Diversity Index) per sample point in remnant and paddock areas at each study site ($F = 8.294$, $P = <0.001$). Games-Howell post-hoc test results illustrated by letter code, with means sharing the same letter not significantly different.

3.3.2 Species Composition

The ordination analysis illustrated large differences in composition between old-field and remnant vegetation at each study site. The stress levels associated with this analysis were consistently low, suggesting that the final ordination provided an accurate representation of the initial similarity matrix. ANOSIM for overall site composition revealed a Global R-value of 0.64 and a P-value of 1.6% (0.016), illustrating that significant differences were

present (Figure 3.5). Remnant vegetation composition was relatively similar between all of the study sites, with the exception of Torquata Ridge (Figure 3.5). The paddock species composition of the two farming sites was most dissimilar to that of the remnants. In terms of similarity, the old-field vegetation composition at Bob's Bush was intermediate to that of the remnants and the old-fields of the two more recently abandoned sites (Figure 3.5).

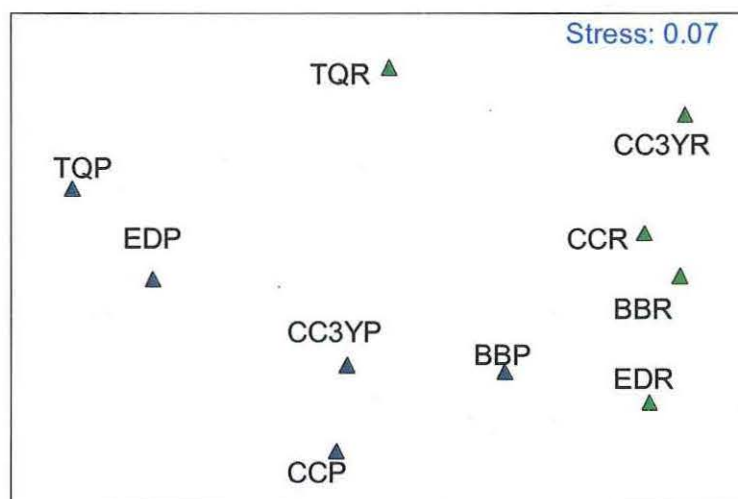


Figure 3.5: Ordination illustrating species composition in remnant and paddock vegetation at each study site overall by mean sample point (Global $R = 0.64$, $P = 0.016$).

Dissimilarity between gradsects was also high between the paddock vegetation at each of the study sites, as illustrated by ordination and ANOSIM results (Figure 3.6). Dissimilarity was most pronounced between the two sites currently being farmed and the three abandoned sites, while the two farming sites exhibited very similar composition (Figure 3.6). The ordination displayed a strong trend across the study sites between paddock vegetation composition and age since abandonment from left to right in the ordination space (Figure 3.6). Ediegarrup Gradsect 1 was more similar to the abandoned sites, likely due to the presence of a native grass species of the genus *Austrodanthonia*, common also to the abandoned paddocks.

The paddock vegetation of Gradsect 1 at Cowboy Country (1-year-old) displayed very different species composition to the other two gradsects, illustrating significant within site variation (Figure 3.6). Cowboy Country (3-year-old) displayed similarity to both the one-

year-old site and Bob's Bush (Figure 3.6). The three gradsects at Bob's Bush displayed similarity in paddock species composition but it was not very strong (Figure 3.6). It should also be noted that Torquata Ridge Gradsect 1 was not included in the ordination analysis as an individual data point. It had been ripped recently and did not contain any vegetation, so could not be included in the similarity matrix.

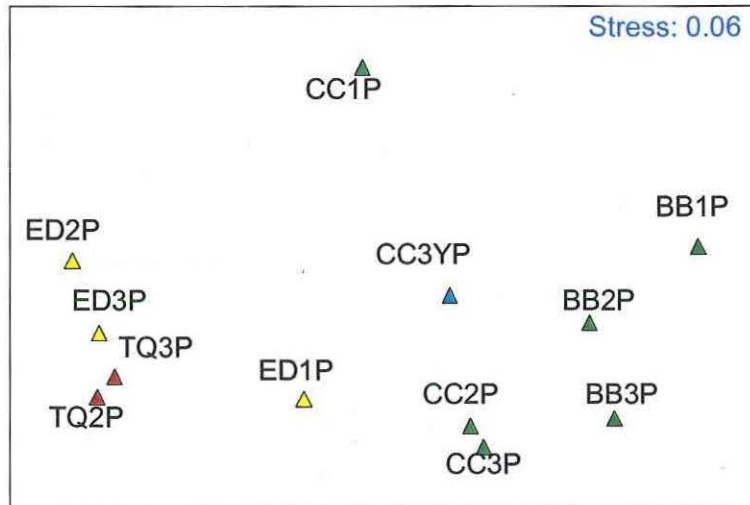


Figure 3.6: Ordination displaying similarity of species composition in paddock vegetation of individual transects at each study site by mean sample point (Global $R = 0.596$, $P = 0.005$).

Despite an overall similarity being illustrated between the paddock vegetation at Bob's Bush and remnant vegetation in Figure 3.5, strong definition between individual remnant and paddock sample points is displayed at Bob's Bush in Figure 3.7. Two of the old-field sample points (Gradsect 1 – SP4 and 5) were similar to the remnant areas, however the other sample points were clustered some distance from the remnant samples (Figure 3.7).

The vegetation at sample points 4 and 5 displayed a similar species arrangement to that of the remnants at the 26-year-old site. They were dominated by relatively closed Eucalypt overstorey, with an underlying vegetation layer dominated by *Boronia*, *Verticordia* and Restionaceae species, which was not observed in other old-field sample points (Table A.1).

Similarity between old-field sample points was also high, despite being illustrated in Figure 3.6 as moderate. Remnant sample points generally exhibited high similarity, however those

from Gradsect 2 were very isolated in terms of species composition (Figure 3.7). This pattern in species composition also existed between remnant and paddock sample points at the three-year-old and one-year-old sites.

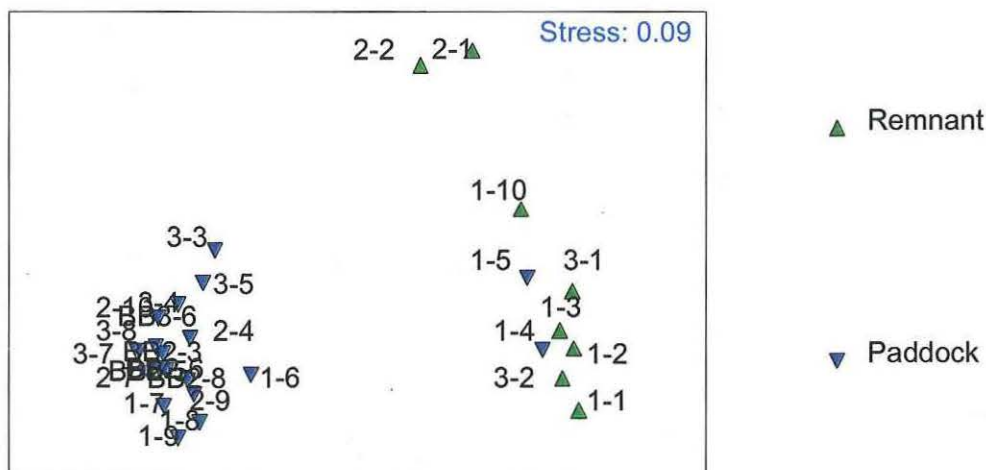


Figure 3.7: Ordination illustrating similarity of species composition between remnant and paddock sample points at Bob's Bush (Global R = 0.815, P = 0.001).

The pattern observed in the presence of native and exotic species played an important role in overall species composition. As illustrated in Figure 3.8, a significant difference existed between native species richness in the remnant and paddock areas at each study site, except for the three-year-old site and Torquata Ridge. A trend in increasing native species richness with increasing time since abandonment was observed (Figure 3.8).

Although introduced species were present at each study site, numbers were generally low within the abandoned sites. An average of less than one species occurred per sample point in the old-fields at Bob's Bush, with the three-year-old site containing a slightly higher number (Figure 3.8). The one-year-old site contained more exotic species per old-field sample point than the other two abandoned sites, but it was not a significant result (Figure 3.8). When compared to Figure 3.3 it is evident that the trends observed in total old-field species richness are somewhat masked by the influence of a higher number of exotics in the one-year-old site and the two farming sites (Figure 3.8).

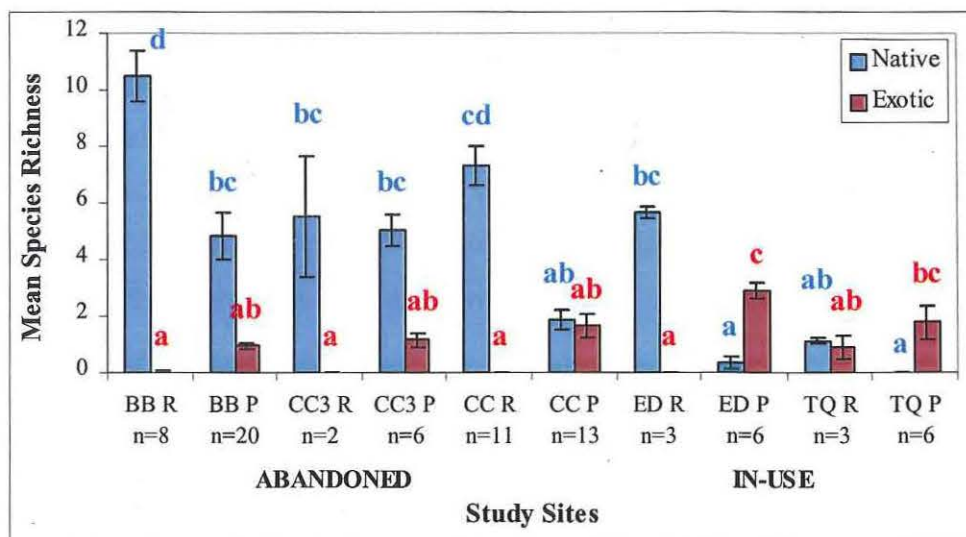


Figure 3.8: Mean sample point species richness of natives ($F = 14.881$, $P = <0.001$) and exotics ($F = 10.612$, $P = <0.001$) in remnant and paddock areas at each study site. Games-Howell post-hoc test results illustrated by letter code, where means sharing same letter are not significantly different and different colours show different tests.

The paddocks at the two currently farmed sites contained a much higher proportion of exotic species per quadrat than those at the abandoned sites (Figure 3.9), with introduced pasture species such as *Trifolium subterraneum* (Clover) and *Hordeum leporinum* (Barley Grass) dominating. The presence of exotic species was confined primarily to the paddock areas in each of the three abandoned sites, however the remnant at Bob's Bush contained a very small proportion of *Solanum nigrum* (Black-berry Nightshade). The only remnant containing a large proportion of introduced species was that of Torquata Ridge (Figure 3.9).

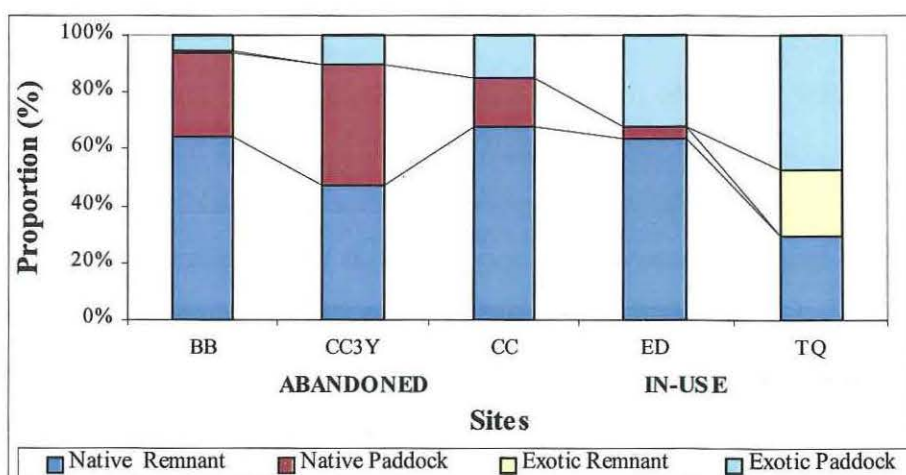


Figure 3.9: Proportion of native and exotic species in remnant and paddock areas at each study site, by mean species richness per quadrat.

A number of species were observed as dominating the composition in the paddock areas at each study site. *Austrodanthonia sp. 1* (Wallaby Grass) was very common in the old-fields of Bob's Bush and the two Cowboy Country sites, with up to 95% cover recorded at some quadrats, however it was almost completely absent from the remnants. As indicated earlier, moderate *Austrodanthonia sp.1* cover was also observed along Gradsect 1 at Ediegarrup but it was otherwise absent from the currently farmed sites.

Apart from a high cover of *Austrodanthonia*, the paddock vegetation at Bob's Bush was dominated by *Gastrolobium parvifolium*, *Davesia retrorsa*, a number of *Grevillea* species, including *G. pectinata*, *G. nudiflora* and *G. patentiloba*, an *Acacia* species with a sprawling growth habit (*Acacia sp. 2*), sporadic Eucalypts (2-3 species) and *Banksia media*. The most conspicuous characteristic of this vegetation was that it was extremely patchy, with clumps of plants occurring at irregular intervals.

On the other hand, vegetation pattern in the Cowboy Country (3yr-old) old-field was characterised by three very distinct belts of vegetation occurring parallel to the remnant that were dominated by single species. The belt in closest proximity to the remnant was dominated by *Goodenia scapigera* (White Goodenia), then *Haloragodendron glandulosum* (Raspwort) became dominant, followed by a particularly wide belt of thick *Acacia harveyi* growth that dominated the central depression between the large spongolite breakaway to the east and the more isolated breakaway to the west (Figure 3.1).

In contrast, the vegetation of the Cowboy Country (1yr-old) old-fields was impoverished. By far the most dominant species present was Wallaby Grass, with native species such as *Carpobrotus disphyma* (Native Pigface) and *Kennedia prostrata* (Running Postman) often present. A number of exotic species such as *Polygonum arenastrum* (Sand Wireweed) and the aforementioned introduced pasture species were also common.

The composition observed throughout the remnants at each of the study sites was very similar and corresponded with the site descriptions of vegetation given in Chapter 2. The broad category of Mallee heathland could be applied to the remnant vegetation inhabiting each of the sites. The overstorey was dominated by *Eucalyptus* species, with *E. pluricaulis*,

E. annulata, *E. floctoniae* and *E. thamnoides* particularly common and interspersed with *Banksia media*. The underlying shrub layer was dominated by a wide range of *Melaleuca* species, however *M. undulata*, *M. hamata* and *Melaleuca* sp. 1, 2, 3, and 4 were most frequently observed. A number of *Verticordia*, *Boronia*, *Grevillea*, *Hakea* and Epacrid species were also relatively common shrubs, ranging in size from very compact to large. The understorey layer was dominated by species from the Restionaceae and Lepidosperma.

3.3.3 Structural Characteristics

Notable differences were observed in vertical structure between remnant and old-field vegetation at each site, as illustrated by the number, type and cover of strata. Structural complexity (number of strata) was much higher in remnants than in corresponding paddock areas at each study site (Figure 3.10). The structural complexity of the paddock vegetation was similar between Cowboy Country (3yr-old) and Bob's Bush, however the number of strata at Cowboy Country (1yr-old) was significantly less than the two older sites and was only slightly greater than that of the two farming sites (Figure 3.10).

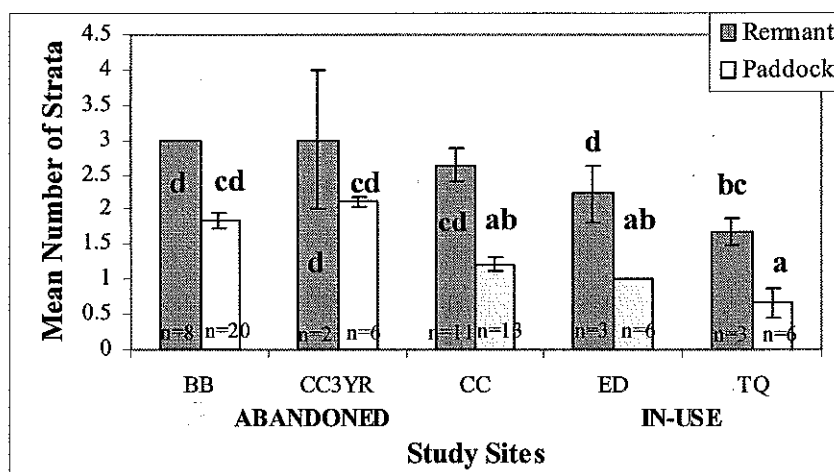


Figure 3.10: Comparison of the mean number of strata in remnant and paddock areas at each study site, by sample point ($F = 17.833$, $P = <0.001$). Games-Howell post-hoc test results by letter code, where means sharing same letter not significantly different.

The cover of each of the strata types, expressed in Figure 3.11 as a percentage proportion of the total cover, again illustrated a strong distinction between the remnant and paddock vegetation at each study site. Understorey vegetation predominated in the paddock areas, as opposed to trees in the remnants and Bob's Bush lacked a tall shrub layer (Figure 3.11).

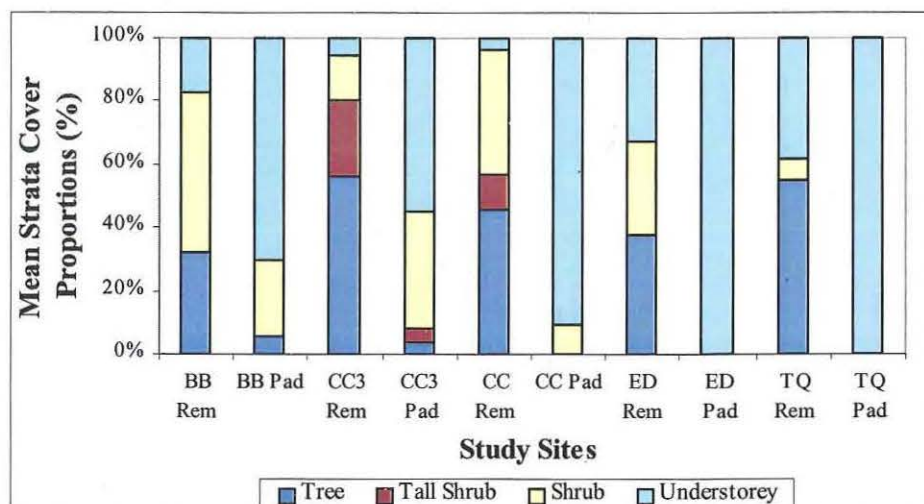


Figure 3.11: Comparison of the proportion of strata type cover (%) in remnant and paddock areas at each study site, by quadrat mean.

3.3.4 Life-form

The Raunkiaer life-form classification revealed that phanerophytes dominated the remnant areas at each study site, in the form of microphanerophytes and nanophanerophytes. The paddock areas however, displayed much more variation in the relative proportions of life-forms between and within study sites (Figure 3.12).

The life-form spectra for Bob's Bush illustrated a close resemblance between the remnant and old-field vegetation (Figure 3.12). Nanophanerophytes predominated in both areas, with microphanerophytes also present in similar proportions. However a much greater proportion of chamaephytes and hemicryptophytes existed in the paddock area than in the remnant (Figure 3.12). A comparison between the two Cowboy Country sites revealed very similar life-form spectra for the remnant vegetation at both sites, however considerable difference was observed between the paddock areas (Figure 3.12). Phanerophytes and chamaephytes were commonly observed at the three-year-old site, while hemicryptophytes and therophytes were much more common at the one-year-old site (Figure 3.12).

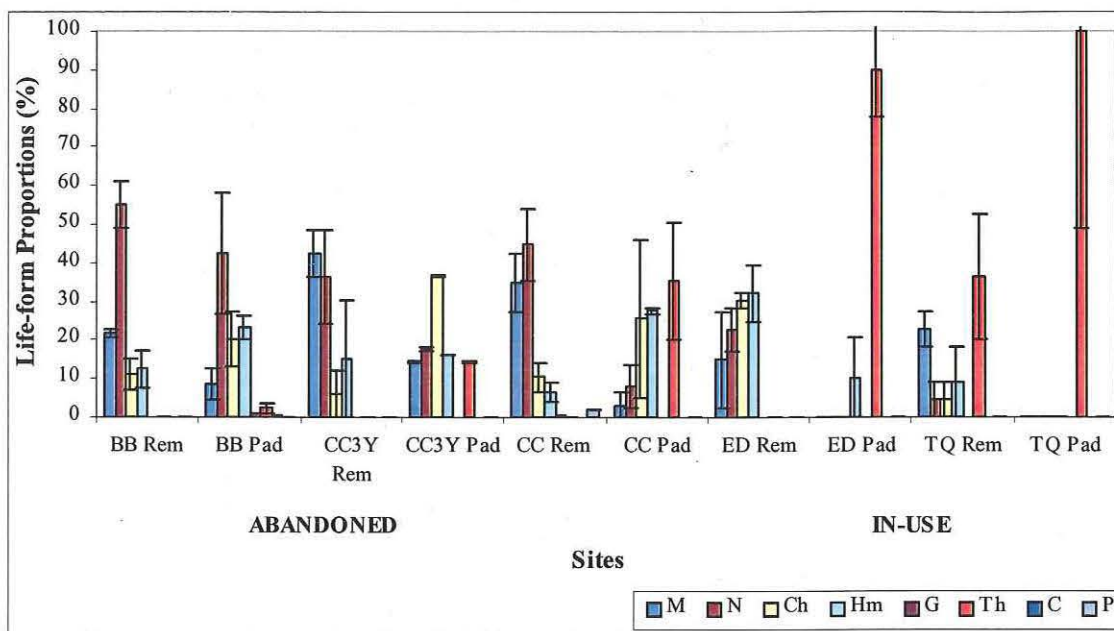


Figure 3.12: Raunkiaer life-form spectra for remnant and paddock vegetation at each study site by mean occurrence per quadrat, expressed as a percentage (\pm SE).

The most distinctive characteristic of the life-form spectra for the two currently farmed study sites was the predominance of therophytes (annual species) in the paddock areas (Figure 3.12). Apart from a small proportion of hemicryptophytes at Ediegarrup, in the form of *Austrodanthonia sp. 1*, no other life-form was recorded (Figure 3.12). In addition, the remnant vegetation of Torquata Ridge displayed proportionately very different life-form spectra to that of the other study sites (Figure 3.12).

In addition to Raunkiaer life-form classification, a comparison of annual and perennial species illustrated differences in life-form characteristics between study sites. A strong trend was evident between decreasing age since abandonment and increasing annual species richness in paddock areas, as illustrated in Figure 3.13.

At each of the study sites, the number of perennial species in the remnant area was greater than that of the corresponding paddock area, however the only significant differences occurred at Bob's Bush and the one-year-old Cowboy Country site (Figure 3.14). This comparison also indicated that although total species richness was higher in the old-field than the remnant at the three-year-old Cowboy Country site, the remnant contained a slightly higher number of perennial species (Figure 3.14).

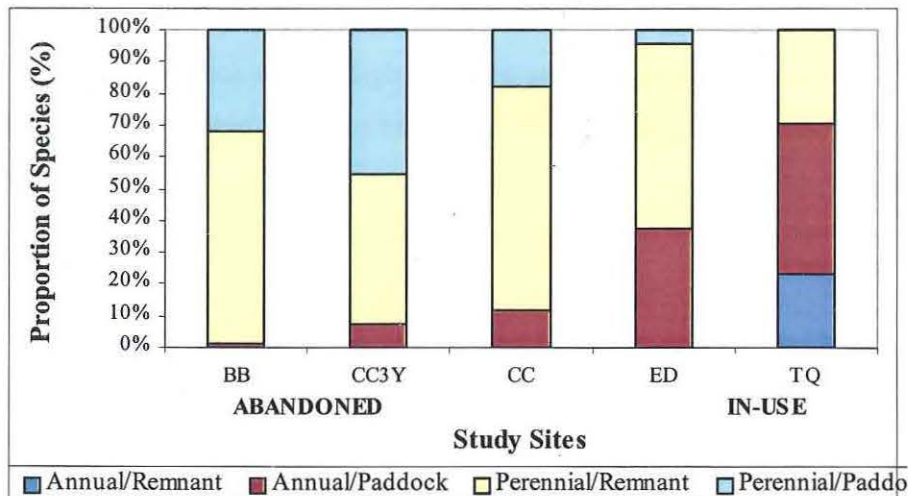


Figure 3.13: Mean annual and perennial species richness in remnant and paddock areas at each study site by quadrat, expressed as a percentage.

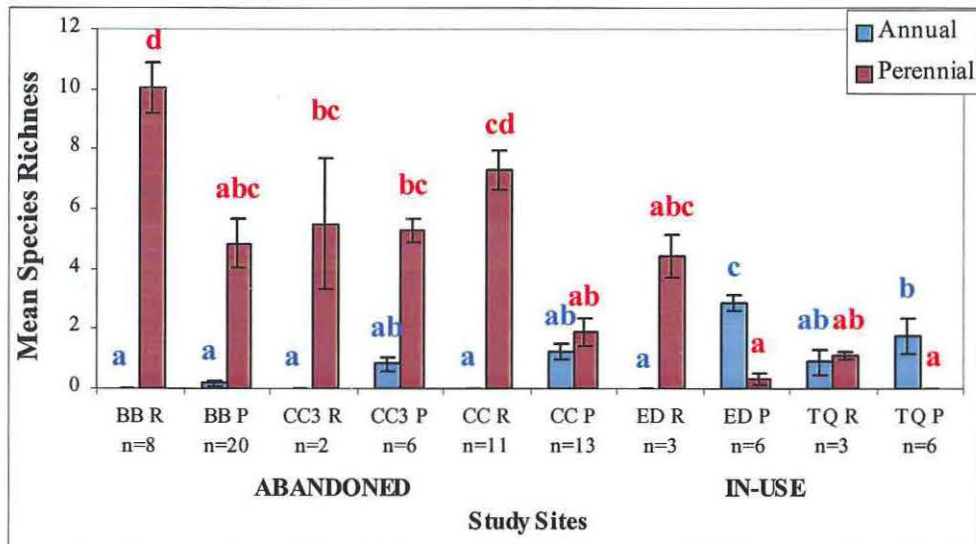


Figure 3.14: Richness of annual ($F = 14.707$, $P = <0.001$) and perennial species ($F = 12.94$, $P = <0.001$) in remnants and paddocks at each study site by mean sample point. Games-Howell post-hoc test results illustrated by letter code, where means sharing same letter are not significantly different and different colours show different tests.

3.3.5 Soil Seed Bank Assessment

The results of the soil seed bank assessment by way of germination trials were represented simply as the total number of individuals observed each week. Declines in the graphs represented death of individuals (Figure 3.15 & 3.16). The germination trials revealed a lack of germination in the remnant samples from the three abandoned sites over the seven-

week period (Figure 3.15). Conversely, high germination rates were generally noted in the samples taken from paddock areas. High standard error was displayed across the paddock sites, illustrating considerable variation between individual samples (Figure 3.15).

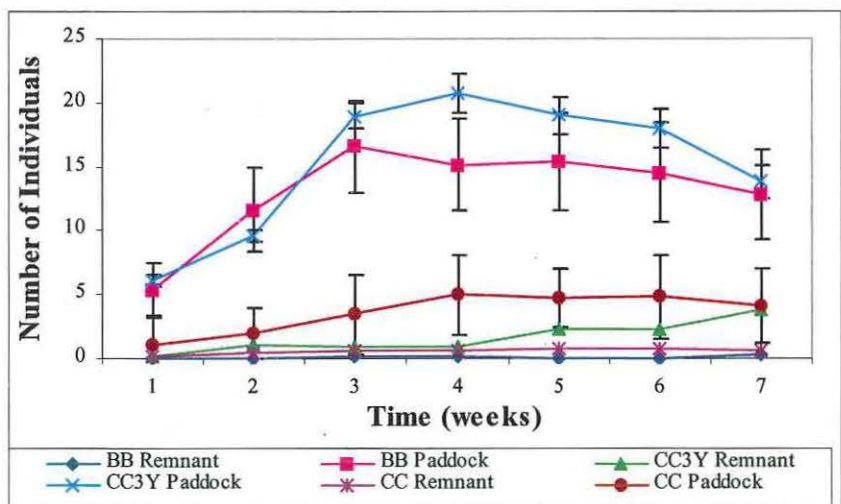


Figure 3.15: Mean germination rates of individual seedlings within remnant and paddock areas at each of the abandoned sites, by quadrat sample.

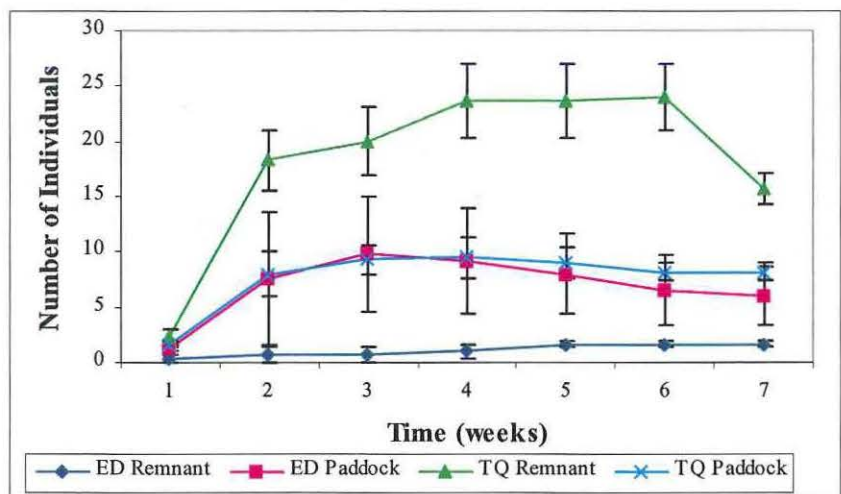


Figure 3.16: Mean germination rates of individual seedlings within remnant and paddock areas at the two sites currently being farmed, by quadrat sample.

Germination in the two sites currently under cultivation differed considerably from those of the abandoned study sites (Figure 3.16). The inhibited germination in the remnant areas at Bob’s Bush and Cowboy Country was not observed at Torquata Ridge but to some degree at Ediegarrup. In fact the most rapid and abundant germination observed was that of the remnant at Torquata Ridge (Figure 3.16). Similar germination rates occurred in the paddock

samples at both of the farmed sites (Figure 3.16). Again, standard error indicated considerable variation between samples.

It was evident from the results of the germination trials that greater germination of native species was occurring in the paddocks of Bob's Bush and Cowboy Country (1yr-old) than in Cowboy Country (3yr-old) or the two farming sites (Figure 3.17). Conversely, a much higher number of exotic species were observed in the two currently farmed sites than in the abandoned sites, particularly in the remnant at Torquata Ridge (Figure 3.17).

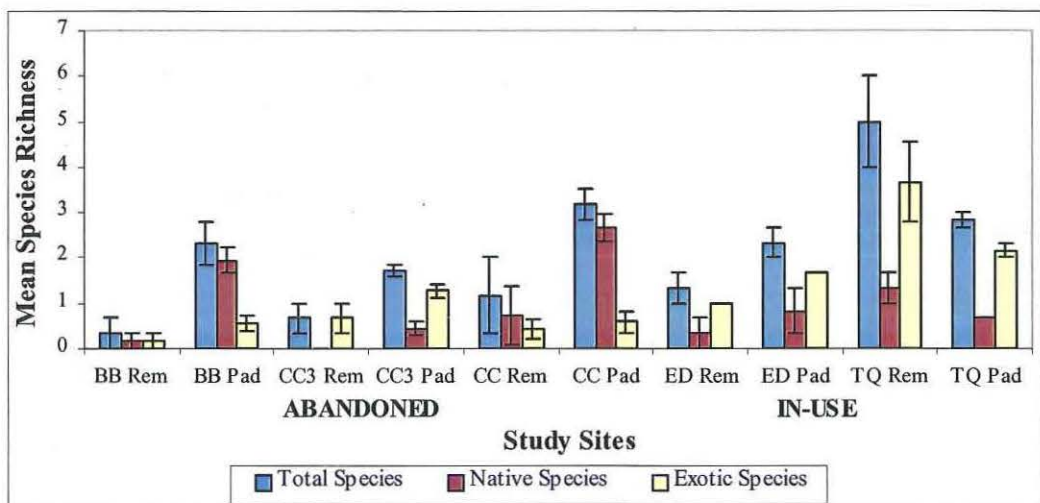


Figure 3.17: Comparison of the total, native and exotic species richness observed in the remnant and paddock samples across all sites by quadrat sample mean.

Positive identification of a number of germinants occurred, including the native species *Austrodanthonia*, *Grevillea pectinata*, *Carpobrotus disphyma* and *Maireana brevifolia* and the introduced species *Hordeum leporinum*, *Lolium sp.1*, *Trifolium subterraneum* and *Arctotheca populifolia*. The most common germinant in paddock samples at Bob's Bush and Cowboy Country was *Austrodanthonia sp. 1*. An encouraging observation was that *Grevillea pectinata* seedlings were common in the paddock samples of Bob's Bush.

3.3.6 Proximity to Remnant

In general, a negative trend was observed between distance from remnant vegetation and the species diversity of paddock vegetation, as illustrated by species richness and the Shannon-Weaver Diversity Index (Figure 3.18 & 3.19).

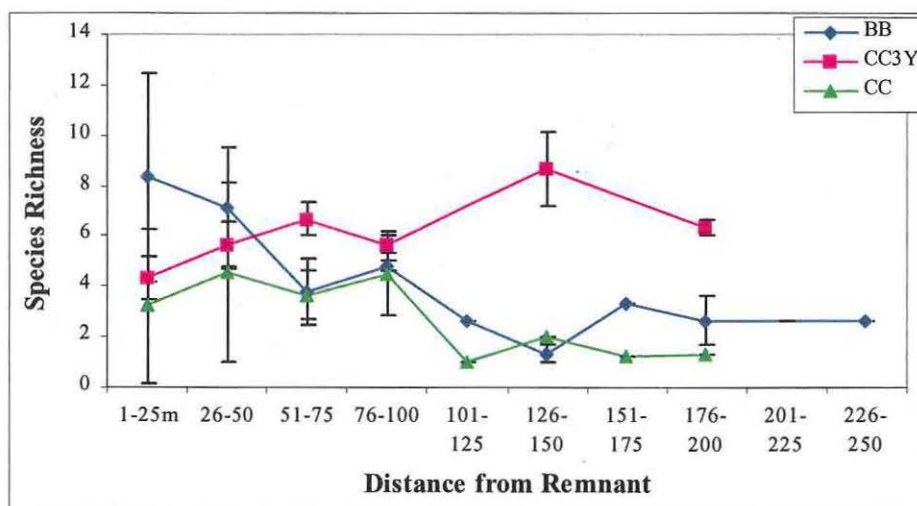


Figure 3.18: Trends between mean species richness and proximity to remnant vegetation in abandoned paddock areas at Bob's Bush, Cowboy Country (3yr) and Cowboy Country (1yr), by sample point.

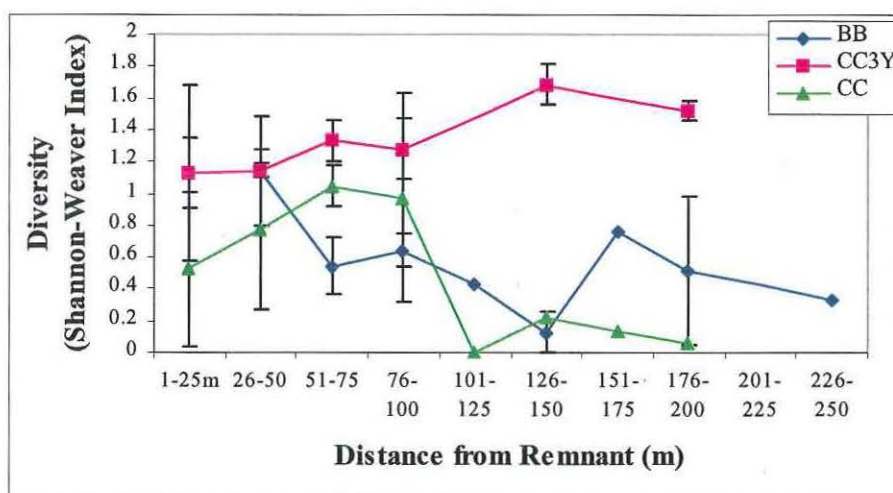


Figure 3.19: Trends between mean species diversity (Shannon-Weaver Diversity Index) and proximity to remnant vegetation in abandoned paddock areas at Bob's Bush, Cowboy Country (3yr) and Cowboy Country (1yr), by sample point.

The trend of decreasing species richness and diversity with increasing distance from remnant vegetation was particularly evident at the one-year-old Cowboy Country site, however the three-year-old site displayed an opposing trend, with diversity increasing gradually with distance from remnant (Figure 3.18 & 3.19). Another conspicuous trend was that of increasing standard error with proximity to remnant vegetation, suggesting greater variability of paddock vegetation with proximity to remnants (Figure 3.18 & 3.19).

Paddock diversity within Bob's Bush was lower than that of the three-year-old site and only slightly higher than the one-year-old site (Figure 3.18 & 3.19).

Changes in species composition along a gradient of increasing distance from remnant did not reflect a universal trend across the study sites. Considerable variation in composition patterning was observed between the three transects at Bob's Bush (Figure 3.20). Species composition change at Gradsect 3 illustrated a gradual shift between those sample points located further away from the remnant and those closer to the remnant (Figure 3.20). Gradsect 2 illustrated a very different pattern, with all sample points along the distance gradient clustered together. The pattern at Gradsect 1 was less distinct, but it did show some graduation in species composition shift along the distance gradient (Figure 3.20).

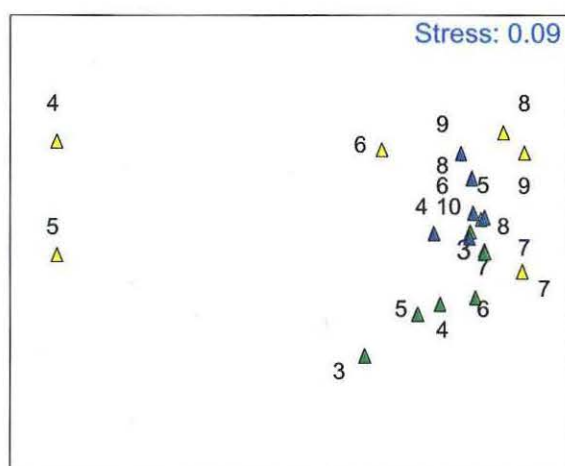


Figure 3.20: Ordination illustrating species composition pattern change in relation to distance from remnant at Bob's Bush. Yellow = Gradsect 1, Blue = Gradsect 2 and Green = Gradsect 3.

The species composition pattern at the three-year-old Cowboy Country site illustrated some graduation in species composition across the distance from remnant gradient, but the trend was not strong (Figure 3.21). The sample points representing a greater distance from remnant were clustered relatively close together, with the sample point representing the greatest distance from the remnant (sample point 8) showing more similarity to the closest position to the remnant (sample point 3) than others of closer proximity (Figure 3.21).

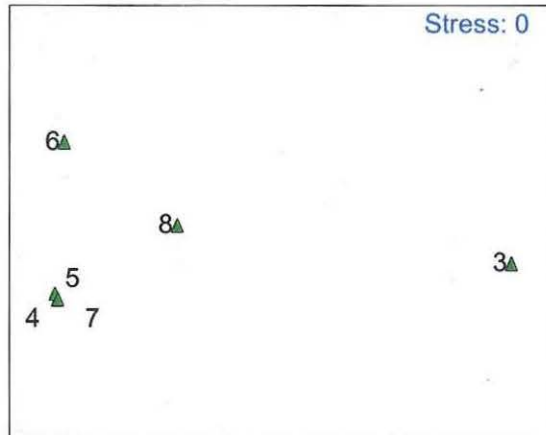


Figure 3.21: Ordination illustrating species composition pattern change in relation to distance from remnant at Cowboy Country (3yr-old).

The patterning at the one-year-old Cowboy Country site also varied between the three gradsects (Figure 3.22). Gradsect 1 illustrated a gradual change in species composition with distance from remnant, while the sample points of Gradsects 2 and 3 were very closely arranged (Figure 3.22).

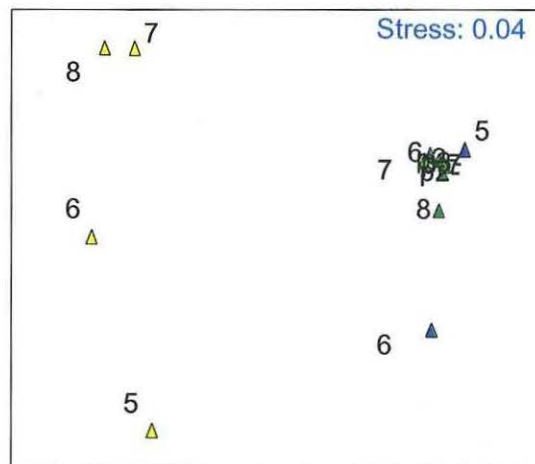


Figure 3.22: Ordination illustrating species composition pattern change in relation to distance from remnant at Cowboy Country (1yr-old). Yellow = Gradsect 1, Blue = Gradsect 2 and Green = Gradsect 3.

3.5 DISCUSSION

From the analysis of floristic characteristics and vegetation patterns between and within remnant and old-field areas at the three abandoned sites, it is evident that old-field recovery of native vegetation has not progressed at a rapid rate, but neither has it been static. Trends across most floristic characteristics indicated time since abandonment played a significant role in the progression of old-field recovery. The site abandoned 26 years ago was progressing towards a state comparable to the original (remnant) vegetation, while the three-year-old and one-year-old sites were exhibiting traits of earlier successional stages and expressed greater similarity to the two currently farmed sites.

Very different patterns in species diversity existed between the old-fields at the three abandoned sites. Total species richness in the old-fields at Bob's Bush was considerably higher than that of the two younger sites, however the mean species richness and diversity by quadrat was less than that of the three-year-old site. This disparity between overall diversity and sample point diversity within the old-field at Bob's Bush indicates high beta diversity. Beta diversity represents change in species composition (species turnover) that takes place along an environmental gradient within a community (Burgman & Lindenmayer, 1998). It relates to tolerance ranges of individual species as well as the degree of environmental change along a gradient (Specht & Specht, 1999). Narrow ecological tolerance ranges of the species found in a community equates to high species turnover/beta diversity. When species turnover is high, the communities observed at different points along a gradient are dissimilar (Specht & Specht, 1999).

In comparison, the species composition of the old-fields at the three-year-old and one-year-old paddock areas was much more uniform, culminating in higher local (quadrat) diversity, but lower overall diversity. This low beta diversity results from the presence of species with broader ecological tolerance ranges than those at Bob's Bush and a more uniform environment (Burgman & Lindenmayer, 1998). The high point diversity in the three-year-old old-field resulted from a high number of exotic species, with very little difference in native species diversity at the local scale between it and the 26-year-old site.

The pattern observed in paddock species composition across all five study sites indicated that the vegetation of the one-year-old and three-year-old sites was still similar to the currently farmed sites, while Bob's Bush was beginning to show similarity to the remnant vegetation. This demonstrates the importance of age since abandonment in influencing species composition as well as overall species richness and indicates different stages of succession at each abandoned site. Extensive Northern Hemisphere study indicates that time since abandonment is one of the most important factors in the progression of old-field succession and recovery, as it enables sufficient time for recovery of disturbed soils and the dispersal of less disturbance-tolerant species (Bazzaz, 1996).

The importance of time since abandonment for passive regeneration on old-fields in the central Wheatbelt near Kellerberrin was also identified by Abensperg-Traun, Arnold, Steven, Atkins and Hobbs (1996). Properties ranging from 20 to 60 years since abandonment were assessed in terms of regeneration of vegetation structure and species diversity. It was found that both structure and diversity were high after 20 years of abandonment and continued to improve with increasing time since abandonment (Abensperg-Traun *et al.*, 1996).

The species colonizing the old-fields at Bob's Bush were generally adapted to more stable environments, for example *Grevillea nudiflora* (Trailing Grevillea). This species is very rarely observed as colonizing disturbed areas (Barrett, Keighery, Makinson, Molyneux & Stajsic, 2000) and was common to the old-fields at Bob's Bush, suggesting that the level of disturbance at this site is not high. The species dominating the paddock region of the three-year-old site were predominantly colonizing species and introduced species remaining from past pasture and cropping. *Goodenia scapigera* was extremely common at the three-year-old site. This species is a coloniser characteristic of recently burnt or highly disturbed areas (Ericson, George, Marchant & Morcombe, 1973). The other two dominant species at this site included *Acacia harveyi* and *Haloragodendron glandulosum*, also characteristic of disturbed habitats (Western Australian Herbarium, 1988). *G. scapigera* was also observed at Bob's Bush old-fields, but in very low numbers, suggesting a decline in the population of the species in response to a less disturbed environment. The one-year-old site contained a large proportion of annual species.

The similarity between the paddocks at Bob's Bush with remnant vegetation in comparison to the younger sites could also be directly related to its brief farming period. The property was only under cultivation for approximately 2 years during the 1970s so disturbance of the existing soil seed bank and rootstock would have been minimal. In comparison, the two sites at Cowboy Country were farmed continually since 1967 until their recent abandonment. The impacts of prolonged agricultural disturbance, such as compaction of the soil by stock and machinery and the ripping of the soil in preparation for cropping can have serious impacts on germination capacity of the soil seed bank (Zimmerman, Pascarella & Aide, 2000). In addition, seedlings are likely to be damaged when they germinate in agricultural soils, particularly by livestock grazing or trampling (Milton, Dean, Plessis & Siegrfried, 1994). Over an extended period this results in loss of seed viability and subsequent depletion of soil seed store (Nepstad, Uhl & Serrao, 1990). This loss of viability over time under cultivation supports the suggestion that time between initial clearing and abandonment is an important factor in subsequent old-field recovery (Levassor, Ortega & Peco, 1990). Bob's Bush was only under cultivation for a short period and a lot of the regeneration observed there can be traced back to the regeneration that occurred in the few years post abandonment.

This depletion of soil seed store does not seem to have occurred at the three-year-old site. After only three years of abandonment, it is exhibiting prolific growth of *Acacia harveyi*, *Goodenia scapigera* and *Haloragodendron glandulosum*. These species were absent from the remnant areas, suggesting that recruitment occurred from an existing soil seed bank that was relatively intact. *Acacia* seed is capable of lying dormant in the soil substrate for decades until sufficient disturbance triggers germination (Bell, Plummer & Taylor, 1993). Persistence of soil seed despite prolonged agricultural disturbance has been demonstrated in the central Wheatbelt. An area farmed for 46 years prior to abandonment was observed to have prolific seedling emergence in areas isolated from remnant vegetation, suggesting at least partially persistent soil seed store (Abensperg-Traun *et al.*, 1996).

As previously mentioned, high species turnover was present in the old-fields at Bob's Bush in comparison to that of the two younger sites. This was represented along a gradient of increasing distance from nearby remnant vegetation in Figures 3.18-3.20. On a local scale

(sample point) diversity of Bob's Bush old-fields decreased as distance from remnant vegetation increased and species composition was more similar to the original vegetation in areas of closer proximity to remnant vegetation. In comparison, the differentiation between remnant and old-field vegetation composition at the one-year-old and three-year-old sites was generally more abrupt.

When the species composition patterning at Bob's Bush is considered holistically however, the division between the similarity of remnant and old-field species composition is apparent and the gradients observed between the two are much less evident. Despite this gradient with distance from remnant being identified, there is still a general dichotomy in species composition between remnant and old-field vegetation. Unassisted natural recovery generally results in landscapes dominated by the species from surrounding areas (Whisenant, 1999). The study of recovering agricultural land in Africa revealed that dominant species were predominantly from local areas and had light, wind-blown or bird-dispersed seed, capable of dispersing long distances (Ducan & Chaprnan, 1999). The pattern observed in vegetation composition at Bob's Bush suggests that this typical regeneration pattern is not occurring.

The size and maturity of the majority of plants at Bob's Bush suggested that these individuals have regenerated from a soil seed bank and rootstock existing prior to abandonment, rather than dispersal and subsequent colonisation of species from the remnants. A number of the species dominating the old-fields were observed in nearby remnant areas, however they were generally uncommon. Species common in the old-field and appearing to have regenerated from existing soil seed included *Acacia* sp. 2, *Gastrolobium parvifolium*, *Grevillea nudiflora*, *Davesia retrorsa* and *Banksia media*. Species also able to regenerate from rootstock/lignotuber included a number of Eucalypt species and the very common *Grevillea pectinata* (Barrett *et al.*, 2000).

Newly established seedlings were predominantly observed in close proximity to established plants, indicating that the older, more established plants are producing viable seed. For example, *Gastrolobium parvifolium* seedlings were particularly common around the base of established plants (Plate 3.1b). This preference for recruitment close to the parent plant may

be limiting more dispersive regeneration of plants in the old-fields and may simply perpetuate the same dominant species, rather than remnant species. This regeneration pattern has caused patchiness in the vegetation inhabiting the abandoned paddock areas and supports the results that show high beta diversity (Plate 3.1b). This patchiness may also be related to the interception of dispersing seed (Plate 3.1a). Seedlings take advantage of the modified microclimate created by established vegetation in regenerating areas (McIntyre & Lavorel, 1994). Established vegetation provides shade, more persistent soil moisture, improved soil structure and often protection from herbivory (Hobbs, 2001).

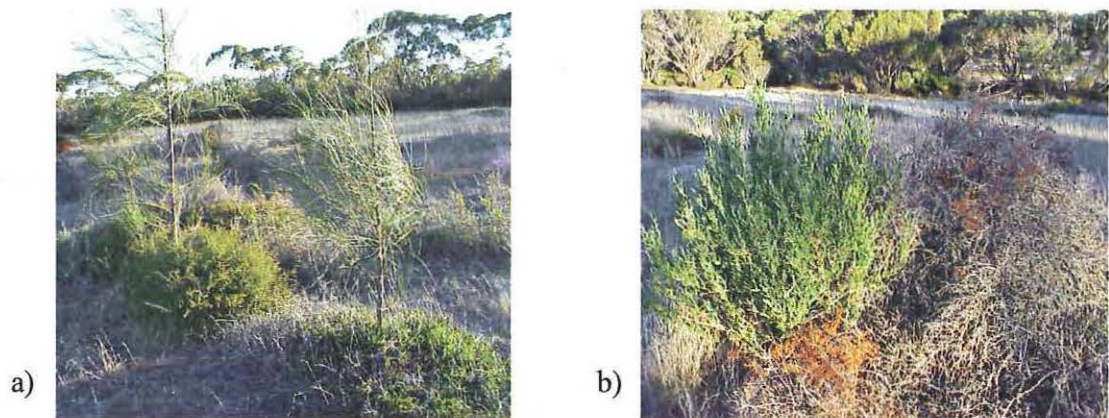


Plate 3.1a): Photograph illustrating the patchiness of regeneration in the Bob's Bush old-fields, with young *Allocasuarina huegeliana* saplings taking advantage of a patch of established *Grevillea pectinata*. b) *Gastrolobium parviflorum* growing from a dead individual of the same species.

There was no evidence to suggest that recent seedlings were emerging as the progeny of the existing mature Eucalypts. This could be attributable to herbivory of emerging seedlings, or to a lack of stimulus in the form of fire required to release this seed, as is the case for a number of mallee species (Wellington, 1989). The natural regeneration of mallee seedlings is normally rare, because they require the occurrence of fire followed by several seasons of high rainfall (Wellington, 1989). No evidence of recent fire was found in the old-fields, as demonstrated by the lack of burn marks on mature individuals of species such as *Banksia media* and Eucalypts, or by burnt logs or charcoal mounds on the soil surface.

The results of the germination trials provided further evidence to suggest that the species native to the study area vegetation required fire to stimulate seed germination. Readily germinable seed was much more available in the soils of the paddock areas than the

remnants, where virtually no such seed was observed. In addition to mallee species, *Melaleuca*, *Banksia* and *Hakea* species were common in the remnant areas at each study site. These and other heathland species often require the heat of fire to stimulate the release of seed from the fruiting bodies (Keith & Bradstock, 1994). Many other species require the smoke resulting from fire to trigger germination (Bell *et al.*, 1993). This fire dependency in remnant vegetation may account for the lack of ready germination of seed in the old-fields.

The germination trials also indicated that seed germination in the soil samples taken from the old-fields at each of the abandoned sites was dominated by *Austrodanthonia sp. 1*. Species of the genus *Austrodanthonia* commonly produce a lot of readily germinable seed, making them proficient colonisers (Western Australian Herbarium, 1988). *Grevillea pectinata* germinants were also common in the Bob's Bush old-field samples, indicating that existing plants are producing viable, readily germinable seed. The native species most commonly germinating in the one-year-old samples was *Carpobrotus disphyma*, a plant adapted to unstable, disturbed soils (Hussey, Keighery, Cousens, Dodd & Lloyd, 1997). Ready germination at the three-year-old site was dominated by introduced species, whereas native species were more commonly observed at the 26 and one-year-old sites. This may prove to be a future management issue, as the competition for resources by fast growing exotic species may inhibit the regeneration of less disturbance tolerant species (Meiners, Pickett & Cadenasso, 2002).

Dispersal mechanisms specific to many of the species were unknown due to insufficient detail in the literature. Most information applied to genus and family rather than individual species, therefore inferences were made from higher taxonomic rank. Specht and Specht (1999) illustrated relative proportions of dispersal mechanisms in heathland and mallee open-scrub vegetation in South Australia, similar in structure and dominant genera to the mallee-heath vegetation of the south-coast of Western Australia (Table 3.3).

Table 3.3: Dispersal strategies in heathland and mallee open-scrub in South Australia, adapted from Specht & Specht (1999). 1. Endozoochory (pass through digestive tract of animals), 2. Censer (slow seed release from fruit shaken by wind), 3. Epizoochory (on fur, etc. of animals), 4. Wind (wind currents) – 4.1 Plumes & 4.2 Wings, 5. Cache zoochory (harvested by ants attracted to edible funicle/elaiosome) 6. Ballistochory (explosive release of seed from fruit), 7. Flotation (in water bodies), FS. Fern spores (in wind).

Plant Formation	Total sp.	Dispersal Category (Proportions expressed as %)								
		1	2	3	4.1	4.2	5	6	7	FS
Heathland	82	16	40	17	10	12	-	5	-	-
Mallee open-scrub	60	17	25	20	7	20	8	3	-	-

Table 3.3 illustrates that the vast majority of heathland species and considerable proportion of the mallee open-scrub are censer (seed shaker) species, in that seed is slowly released from fruit shaken by the wind while still attached to the plant (Specht & Specht, 1999). This strategy facilitates dispersal of approximately two times the height of the plant and as a result, dispersal rates within these species are not high (Hopkins & Griffin, 1984). The vast majority of the Myrtaceae and other dry fruited families in semi-arid plant communities are censors, in particular the Eucalypts (Specht & Specht 1999). In addition, many of these censors retain seed on the plant and fire is required as initial stimulus to release this seed, in a process known as serotiny (Bell *et al.*, 1984). These spatially and temporally restricted dispersal mechanisms in Eucalypt and Melaleuca species may explain the division between the old-field and remnant vegetation, particularly at Bob's Bush.

Acacia species are classified as cache zoochory species, in that their seed is dispersed by ants. Ants are attracted to the elaiosome or aril, an oil body attached to the seed (New, 1984). After the seed is taken below ground and the aril removed, the seed itself is simply abandoned beneath the soils as a waste product (New, 1984). This again indicates the presence of a soil seedbed prior to abandonment, rather than dispersal from the remnants at the three-year-old site. Study into this dispersal method has illustrated that dispersal rarely exceeds 15m from the parent tree (Ness, Bronstein, Andersen & Holland, 2004), so it seems unlikely that the seed has been carried any great distance from remnants. In addition, the Acacia species (*Acacia harveyi*) observed in the old-fields at the three-year-old site was not observed in the remnant vegetation at Cowboy Country.

Austrodanthonia was well established at all three abandoned sites because it disperses by epizoochory and wind, in the manner of most grass species (Specht & Specht, 1999). These

methods facilitate considerably greater dispersal than cache zoochory or censor, enabling more rapid colonisation of disturbed areas (Simon & Macfarlane, 1996). In addition, it is often retained in paddocks as additional pasture, particularly in marginal farming areas (Overheu, 2001). The predominance of *Austrodanthonia* sp. 1 on old-fields may be preventing widespread shrub and tree regeneration between established patches at Bob's Bush. The competition of established perennial grass has been shown to have significant impacts on the regeneration of shrub species (De Broeck, 1988).

Herbivory may also be preventing old-field regeneration at Bob's Bush. There was extensive evidence of the presence of kangaroos and rabbits, in the form of scats, rabbit burrows and observations of individuals. In response, the species that dominated Bob's Bush tended to be unpalatable or very prickly. More palatable species such as *Acacias* and *Eucalypts* are particularly susceptible to herbivory, especially during the seedling phase, which may be preventing regeneration (Tiver & Andrew, 1997). Even species with defence mechanisms, such as adult *Davesia retrorsa* were impacted on (Plate 3.2 a) and b)).



Plate 3.2 a): Natural growth form of *Davesia retrorsa* at Bob's Bush. b) The same species subjected to herbivory at Bob's Bush.

The proportion of native and exotic species was an important indication of the progression of old-field recovery. The fact that exotic species decreased as age since abandonment increased indicated that the health of the native system improved with time (Meiners *et al.*, 2002). The competition for resources between exotic and native species is often identified as a major limitation to native vegetation recovery in degraded remnants throughout the south-west (Panetta & Hopkins, 1991). Vigorous growth of annual grasses such as *Lolium*

rigidum has been shown to cause high rates of native seedling mortality during the first summer following establishment (Panetta & Hopkins, 1991).

Annual species richness also decreased as age since abandonment increased, with the highest diversity observed in the currently farmed sites. The annual species predominating in the paddocks under cultivation were the most commonly observed annuals in the old-fields, indicating that the source of these annuals is soil seed from past farming and not colonisation from surrounding areas. Annual species are capable of persisting for a number of seasons as stored soil seed and emerging readily to take advantage of favourable conditions (Shmida & Burgess, 1988), as evidenced by the germination trials. The annual life-cycle is an adaptation to environments in which disturbance and /or environmental fluctuations means that the chance of long-lived species surviving from year to year is very low (Symonides, 1988). Annuals are capable of colonizing a wide range of environmental gradients in disturbed areas (Epp & Aarsenn, 1988). The fact that annual species contributed very little to the biodiversity of the 26-year-old site indicates that it is approaching a more stable system.

An analysis of functional attributes in addition to a taxonomic description of the vegetation at the abandoned sites is beneficial in assessing the progression of old-field recovery in the context of time since abandonment (Duckworth, Kent & Ramsay, 2000). The rapid decrease in therophytes (annuals) from areas still being farmed, to the area abandoned 26 years ago indicates a shift in life-form dominance in response to lack of disturbance (see Symnoides, 1988). The similar pattern in microphanerophytes and nanophanerophytes between the remnant and old-field areas at Bob's Bush reflected that plants adapted to more stable environments were dominating the old-fields (see Kent & Coker, 1992).

At the three-year-old and one-year-old sites however, the dominant life-forms were those adapted to more unstable conditions and as a result, there was no similarity in life-form spectra between the remnant and old-fields. Hemicryptophytes dominated the one-year-old site, principally due to the presence of the perennial native grass *Austrodanthonia*, as opposed to chamaephytes. Schmida and Burgess (1988) suggest that this is because hemicryptophytes have the ability to capture resources such as soil moisture and sunlight

and convert them rapidly to biomass, as they have greatly reduced perennial shoot organs in comparison to chamaephytes. They are also well adapted to above ground disturbance. Chamaephytes on the other hand must devote a large amount of energy to producing an extensive root system and above ground structure in order to capture resources (Shmida & Burgess, 1988).

There was a general trend in increasing structural complexity of paddock vegetation with increasing age since abandonment, while the remnant vegetation at each study site exhibited much greater complexity than the adjacent paddocks regardless of age. Complexity at the three-year-old site was slightly higher than the 26-year-old site because the vegetation of the former contained a tall shrub layer. The development of more complex vegetation structure and composition is a common feature of late successional communities (Kershaw, 1973). This improvement indicates that old-field regeneration of native vegetation in the study region is progressing towards a more natural system over time.

3.6 CONCLUSIONS

It was evident from the results that as age since abandonment increases, the structural and compositional complexity of the regenerating vegetation progresses, but does not necessarily closely resemble the surrounding native vegetation. Time since abandonment was identified as one of the most important limiting factors to natural recovery, natural meaning no human intervention. This has implications for revegetation, as there is often a time requirement and this natural recovery may simply be too slow.

A consideration of the spatial element as a potential barrier to regeneration, i.e. proximity to remnant vegetation, is important to understanding regeneration pattern (Bazzaz, 1996). It is evident from the results of this research that dispersal mechanisms have an important influence on the progression of natural recovery of native vegetation in the Fitzgerald Biosphere. It was also apparent that remnant vegetation plays a minor role in recovery processes, despite an identifiable gradient between increasing distance from remnant and decreasing diversity. This appears to arise because spatially limiting dispersal mechanisms are characteristic of the remnant vegetation at each site (Specht, 1994a). The importance of

fire for the regeneration of a number of species, particularly mallees, has been highlighted as a potentially important barrier and requires further investigation.

The viability of the soil seed bank and rootstock has significant implications for the degree of germination and establishment following abandonment, particularly areas isolated from remnant vegetation (Abensperg-Traun *et al.*, 1996). Stored soil seed was found to contribute significantly to the regeneration at each site and often accounted for the lack of similarity between existing remnant vegetation and old-field vegetation. In addition, the time elapsing between initial clearing and abandonment appeared to be more important to soil seed viability than time since abandonment.

CHAPTER 4: STATE OF SOIL PROPERTIES

4.1 INTRODUCTION

The aim of this chapter was to assess the potential influences of state of soil properties on the progression of old-field recovery.

In order to carry out this assessment, the state of particular soil properties in areas of remnant and paddock vegetation was analysed and described for study sites across a range of ages since abandonment. It was important to establish the natural state of soils in the area before any interpretation could be made as to the impacts of agricultural practice and the potential for soil to recover from such impacts.

It was also important to identify the strongest trends between state of soil parameters and vegetation composition, especially in the context of time since abandonment and proximity to remnant. This enabled inferences to be made about the relationship between soil condition and regeneration potential of native vegetation on old-fields.

4.2 METHODS

4.2.1 Sampling Methods

The gradsect sampling method was employed as in Chapter 3, section 3.2.1 and sampling was undertaken in every quadrat (i.e. 3 quadrats per sample point).

4.2.2 Field Methods

Surface Compaction

Surface compaction was measured using a spring-loaded penetrometer. A penetrometer measures the force required to penetrate the surface of the soil in pounds per square inch

(Plaster, 1996). Three measurements were taken randomly within each quadrat and averaged. The measurement of surface compaction was pertinent to this research, as surface crusting and compaction as a result of agricultural practices impact on plant establishment and growth (Rendig & Taylor, 1989).

Repellency, Infiltration and Runoff

Water repellency was measured using the timing method as described in Department for Sustainable Natural Resources (1999). The time taken for a drop of distilled water to be absorbed was measured in seconds and assessed according to the criteria specified in Table 4.1. Three replications were carried out in each quadrat and an average was taken.

Table 4.1: Soil repellency class (Department for Sustainable Natural Resources, 1999).

Time Taken to Absorb	Classification
<1 second	Not significant
1-10 seconds	Very low water repellence
10-50 seconds	Low water repellence
50-260 seconds	Moderate water repellence
>260 seconds	Moderate to severe water repellence

The ring method was used to measure infiltration, as detailed in McLaren & Cameron (1996). This method measures the time taken for a specified amount of water to soak into a ring of specified diameter to calculate the infiltration rate (McLaren & Cameron, 1996).

Runoff was measured using a method adapted from Tongway and Hindley (1995). This crude method of measurement provides a basic indication of surface runoff. A set volume of water (500ml) was poured at a set rate (for 30 seconds) onto the soil surface and once the water had soaked into the soil, the total length (cm) it had traversed was measured.

Soil Texture

Soil texture was established for surface soil using field texture analysis, or the bolus test, as described in McDonald and Isbell (1984).

Slope

This was measured in degrees at each quadrat using a clinometer. The measurements were required to provide scope for soil properties such as runoff.

Characteristics of Litter Layer and Soil Surface

Within each quadrat, litter depth and cover, bare soil cover and cryptogam cover was measured. Cover was expressed as a percentage and litter depth was measured 5 times randomly throughout the quadrat and an average value was taken.

The litter layer is an important source of soil organic matter and nutrients essential to plant growth. The amount of bare soil is also an important characteristic, as this has implications for factors such as erosion and soil moisture retention (Tongway & Hindley, 1995). Cryptogams, namely mosses, lichens and liverworts, play an important role in the breakdown and release of organic compounds in the soil and litter beneficial to plant growth and aid infiltration (Tongway, 1994).

Soil Sampling for Laboratory Analysis

Two soil samples were taken randomly from each quadrat. One was sent to an independent laboratory to be analysed for nutrient content and the second was taken to test for organic matter content, electrical conductivity and pH. Each sample was taken randomly to a depth of 15-20cm. The samples were placed in labeled snap-lock plastic bags to prevent loss of soil moisture that could influence analysis.

4.2.3 Laboratory Methods

Preparation of Soil Samples

The soil samples were oven dried at 105 degrees C for 24 hours in aluminum trays and sieved in a 2mm sieve. Wet and dry soil weights were taken and the volume of soil

substrate >2mm and <2mm in diameter was measured. Soil moisture content was measured as part of the drying process, but was not included in the analysis, as one sample was not sufficient to provide a representation of the moisture retention characteristics of the soil. As soil sampling was carried out over a number of days, the temporal variation in rainfall would have affected the results.

CSBP Analysis

Nutrient analysis was carried out by CSBP. CSBP is a fertiliser manufacturing company, however it also conducts soil testing for nutrient levels, catering predominantly for farmers. The expense associated with analysing each quadrat sample individually was unjustifiable, so the samples from the three quadrats in each sample point were pooled and mixed to create a bulk sample for each sample position. This limited data analysis, in that means and standard errors could not be established for individual sample points.

CSBP carried out analysis for ammonia, nitrate, available phosphorus and organic carbon. These variables provide a good indication as to the nutrient cycling processes occurring in the soil substrate. Available phosphorus was extracted from the soil sample using a sodium bicarbonate solution and the concentration was measured colorimetrically (Colwell, 1965). Ammonium was measured colorimetrically using the indo-phenol blue reaction, after being extracted from the soil sample in 1M potassium chloride (Rayment & Higginson, 1992). Nitrate concentration of the soil samples was determined from a single soil/water extract, using a specific ion electrode (Rayment & Higginson, 1992). Organic carbon was determined by first oxidising the organic matter within the soil sample by chromic acid, using the heat of the dilution of the sulphuric acid in dichromate solution to accelerate the reaction. The organic carbon content was then measured colorimetrically in comparison to glucose standards (Rayment & Higginson, 1992). In addition to this, CSBP carried out soil texture analysis based upon the bolus test detailed in McDonald and Isbell (1984) and classed as a numerical scale according to clay content (Duncan, 1992). The results of this analysis were much easier to analyse than the descriptions derived from the fieldwork and displayed very similar results, so the CSBP data was used instead.

Organic Matter Content/Loss on Ignition

Soil organic matter content was established using the 'Loss on Ignition' method (LOI), as detailed in Nelson and Sommers (1996). A portion of each prepared sample was transferred into ceramic crucibles and weighed. The crucibles were then placed in a furnace for 3 hours at 500 degrees C, to burn off the organic matter component. The crucibles were then transferred to a dessicator and allowed to cool to room temperature. The samples were weighed again and from the two weights the organic matter component was measured as a percentage. It should be noted here that the LOI method has the potential to distort results, as it often results in the loss of inorganic soil components. This may explain some of the abnormally high results obtained for a number of study sites (Figure 4.8).

pH and Electrical Conductivity

The pH content of the soil at each site was determined using electrometric measurement by way of a glass electrode pH meter, the most common form of pH measurement (Thomas, 1996). Electrical conductivity (EC) was measured to establish total soil salt content, using a conductivity meter (Purdie, 1998). Each meter was calibrated prior to use. Two replicates of 1:5 water extract were used for the measurement of each variable, with the second pH replicate in Calcium Chloride (CaCl_2). The addition of this solution provides a more accurate representation of the pH in soil solution. A mean value was then established from the replicates.

4.2.4 Data Analysis

ANOVA (Analysis of Variance)

Analysis of Variance (ANOVA) in SPSS was employed to analyse the variation in mean values of each soil variable. One-way ANOVAs of single variables were carried out in SPSS, comparing site means and differences between remnant and paddock means across all study sites.

Bearing in mind the assumptions of ANOVA described in Chapter 3, section 3.2.3, those data sets that did not display homogeneity of variance (<0.05 critical value) were treated with caution and the Games-Howell post-hoc test was used, as it does not assume equal variance when differentiating between means (Dytham, 2003). Again, the Tukey's-b post-hoc test was used to differentiate between means that expressed homogeneity of variance.

Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) in CANOCO was used to assess the strength of trends observed between soil characteristics and vegetation composition between and within study sites. Cover values were used to represent species composition for the reasons stated in Chapter 3, section 3.2.3. All of the soil variables analysed above were included in the CCA analysis following cross-correlation, apart from the soil surface characteristics. In addition, distance and time elements were included in order to place the trends between soil and vegetation into the context of proximity to remnant and age since abandonment.

CCA is a form of constrained ordination, in that the axes are constrained to be linear combinations of explanatory variables (ter Braak, 1986). In this case, the ordination of floristics is constrained by environmental variables. CCA uses weighted averaging to represent how biological variability is explained by environmental variables (Leps & Smilauer, 2003). The strength of this method of analysis is that it displays the biological variability, in this case floristic composition, explained by the environmental data. One of its limitations however, is that cross-correlated variability over emphasises the biological variability (Leps & Smilauer, 2003).

4.3 RESULTS

4.3.1 Soil Parameters

The results of the soil analysis (Figure 4.1 – 4.15) illustrated striking differences in the state of soil properties, both between study sites and between remnant and paddock areas within individual sites. As in Chapter 3, the bars in graphs represent \pm SE throughout the results.

Litter cover was significantly higher in remnants than adjacent paddocks at the abandoned farm sites, however the remnants at Ediegarrup and Torquata Ridge revealed only slightly higher litter cover than the adjacent paddocks (Figure 4.1). Conversely, bare soil cover in the remnants was significantly higher than the adjacent paddocks at these two farming sites (Figure 4.1). No significant difference in cryptogam cover was observed between the sites, with consistently low cover exhibited (Figure 4.1).

The depth of the litter layer was significantly greater in the remnant area of each site than the adjacent paddock, as illustrated in Figure 4.2. The three-year-old Cowboy Country remnant exhibited particularly high results, however it also showed a large standard error, suggesting considerable variability in litter depth (Figure 4.2). When the litter depth values were compared to the cover values illustrated in Figure 4.1, it appeared that the remnants at a number of sites had thick, yet patchy litter distribution, particularly the two currently farmed sites (Figure 4.2).

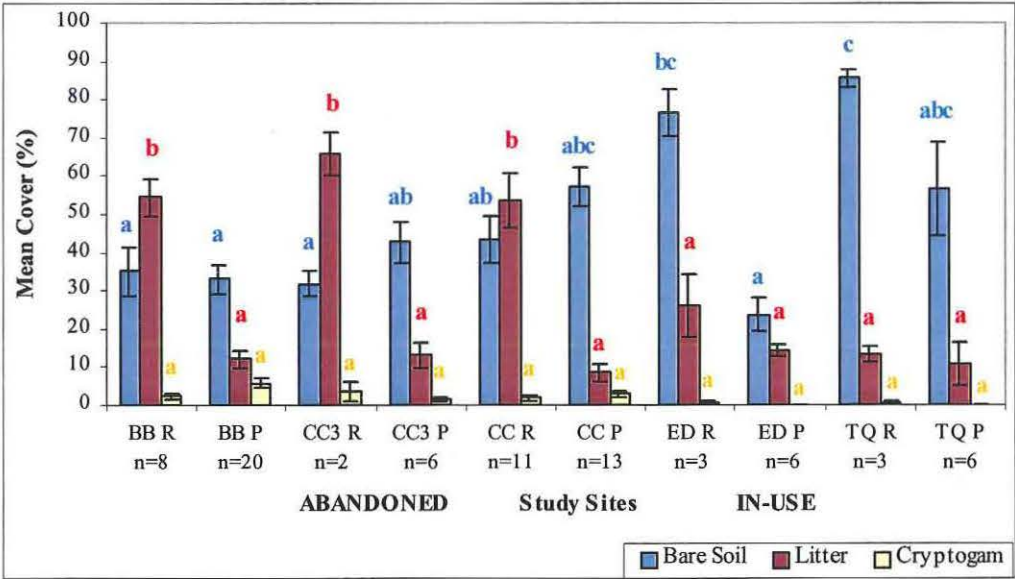


Figure 4.1: Bare soil cover ($F = 5.883$, $P = <0.001$), litter cover ($F = 18.361$, $P = <0.001$) and cryptogam cover ($F = 0.986$, $P = 0.46$) in remnants and paddocks areas at each study site by sample point mean. Games-Howell and Tukey's-b post-hoc test results illustrated by letter code, where means sharing same letter are not significantly different and different colours show different tests.

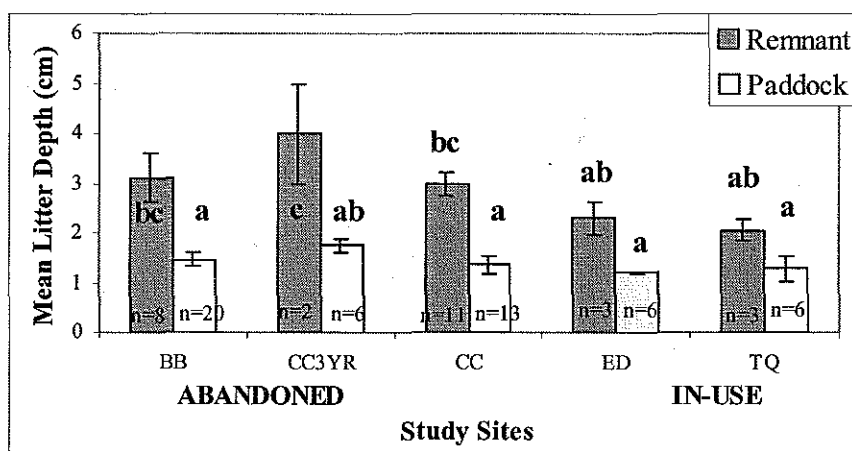


Figure 4.2: Mean litter depth across remnant and paddock areas at all study sites by sample point ($F = 9.199$, $P = <0.001$). Games-Howell post-hoc test results shown by letter code, where means sharing the same letter are not significantly different.

The only significant difference in repellency to water between sites was between the remnant at Bob's Bush and the Cowboy Country (3yr-old) old-field (Figure 4.3). The large standard error at Bob's Bush remnant indicated variation in repellency within the remnant samples. The only emergent trend was that repellency was generally higher in the remnants than in the adjacent paddock areas, however the difference was not strong (Figure 4.3).

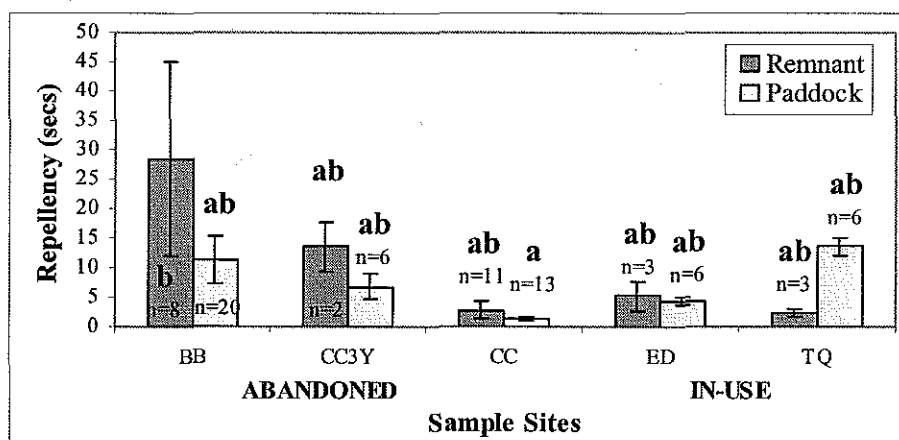


Figure 4.3: Mean repellency to water by sample point between remnant and paddock soils at each study site (F value = 4.081, P value = 0.001). Games-Howell post-hoc test results illustrated by letter code and means with same letter not significantly different.

The results reflected slower infiltration rates in the soils of the remnant areas than those of the adjacent paddocks, with the exception of the one-year-old Cowboy Country site (Figure 4.4). The infiltration rate at Torquata ridge remnant was particularly slow, with a mean

value of almost five minutes. Infiltration rates within the paddock soils of Bob's Bush and Ediegarrup were significantly greater than that of their adjacent remnants (Figure 4.4).

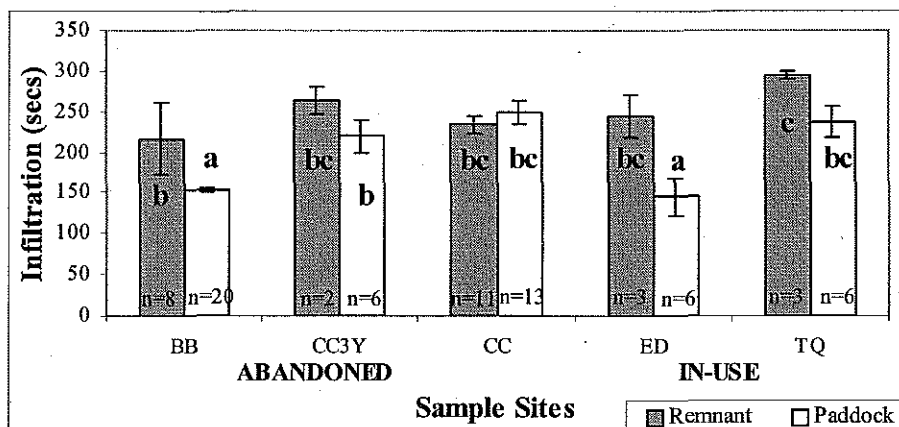


Figure 4.4: Mean infiltration rate by sample point between remnant and paddock soils across all study sites (F value = 5.968, P value = <0.001). Tukey's-b post-hoc test results illustrated by letter code and means with same letter not significantly different.

The trend in surface runoff was similar to that observed for infiltration, in that runoff was consistently higher in the remnant soils at each site than in the adjacent paddock soils. However no significant results were highlighted between or within sites (Figure 4.5)

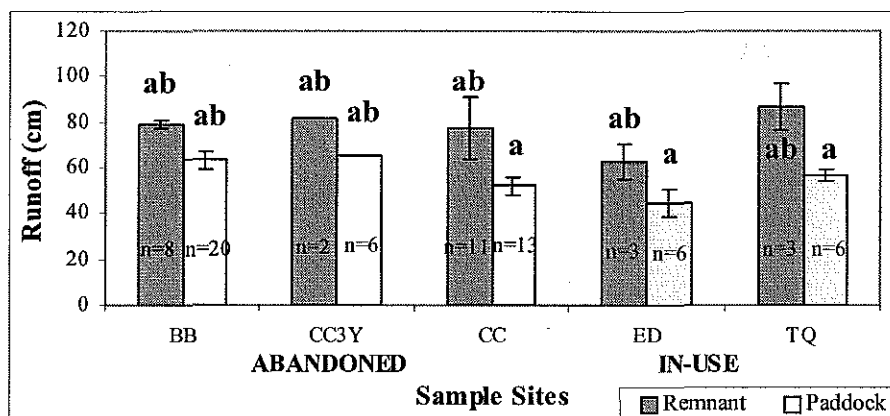


Figure 4.5: Surface runoff for remnant and paddock soils across all study sites, by sample point mean (F = 2.191, P = 0.33). Tukey's-b post-hoc test results illustrated by letter code, where means sharing the same letter not significantly different.

Compaction was consistently much higher in the paddock soils than in the remnants. However the only statistically significant differences were observed between the remnant and adjacent old-field areas at Bob's Bush and the one-year-old Cowboy Country site (Figure 4.6).

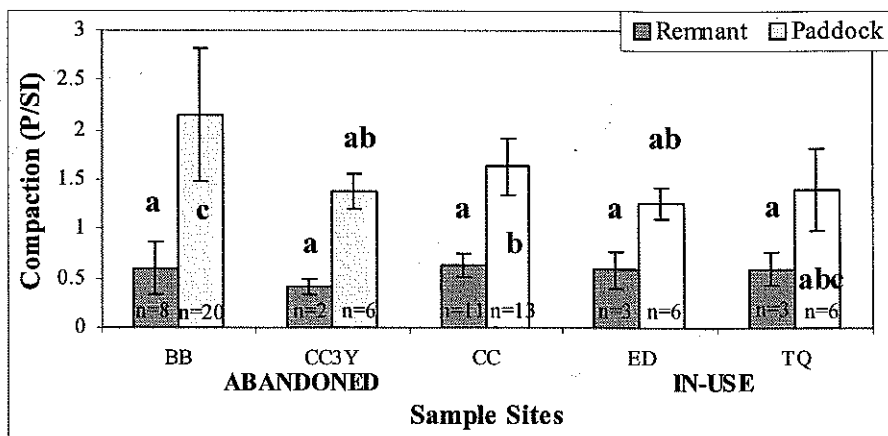


Figure 4.6: Compaction of soils in remnant and paddock areas across all study sites, by sample point mean ($F = 4.624$, $P = <0.001$). Games-Howell post-hoc test results illustrated by letter code and means sharing the same letter not significantly different.

Slope was consistently low across study sites, with the exception of the two Cowboy Country sites (Figure 4.7). Slope in the remnant at the three-year-old study site was significantly higher than at any other site, except for the one-year-old remnant. The huge standard error at the three-year-old site indicated considerable variation in slope within the remnant, in comparison to relatively uniform slope at the other sites (Figure 4.7).

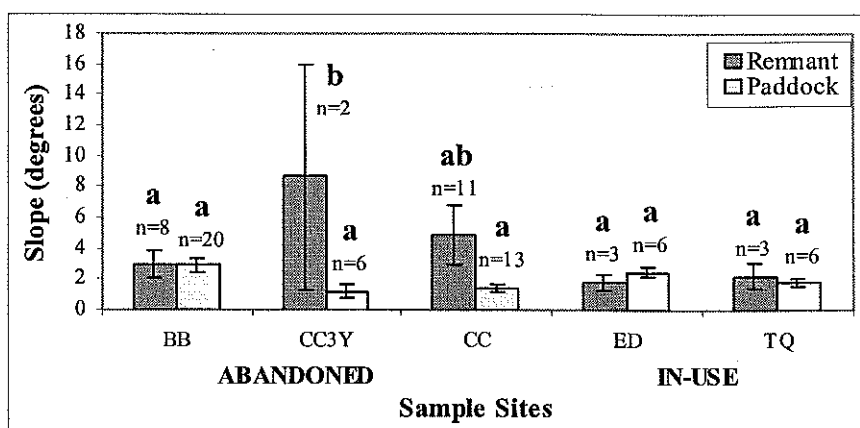


Figure 4.7: Slope of remnant and paddock areas at each study site, by sample point mean ($F = 2.414$, $P = 0.019$). Games-Howell post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

The soil variables measured in the laboratory revealed significant differences between remnant and paddock areas across all study sites. Some of the most striking deviations occurred between the paddock areas of the abandoned and currently farmed sites.

The analysis of organic matter revealed that remnant soils contained more organic matter than the soils of the paddocks at each study site. However this difference between remnant and paddock soils was only significant at the two Cowboy Country sites (Figure 4.8). The organic matter content of the paddock soils at the one-year-old site was comparable to that of the farming sites, but not to the three-year-old site (Figure 4.8). Surprisingly, Bob's Bush comparatively little organic matter in both the remnant and paddock soils (Figure 4.8).

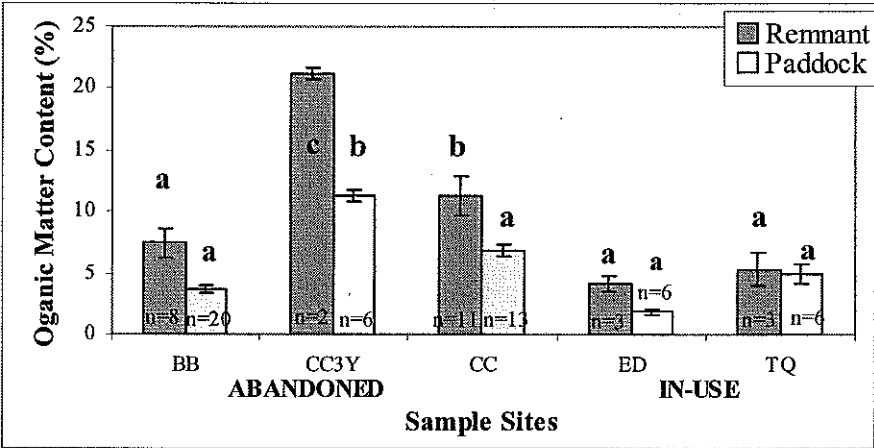


Figure 4.8: Mean organic matter content of soils between remnant and paddock areas at each study site, by sample point ($F = 19.427$, $P < 0.001$). Games-Howell post-hoc test results shown by letter code and means of same letter not significantly different.

pH levels were consistently low across all study sites and did not exhibit a lot of within site variation either, as illustrated by the small standard errors (Figure 4.9). The only notable difference was that the paddock soils of Bob's Bush were significantly less acidic than those of Torquata Ridge (3yr-old) (Figure 4.9).

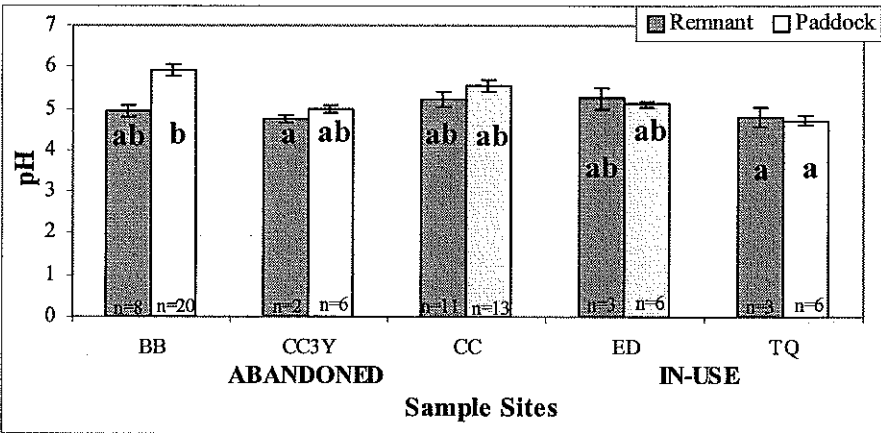


Figure 4.9: pH levels in remnant and paddock soils at each study site, by sample point mean ($F = 5.481$, $P < 0.001$). Tukey's-b post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

Despite revealing highly significant results, the post-hoc test revealed no significant differences in electrical conductivity between the remnant and adjacent paddock soils at each site (Figure 4.10). The two Cowboy Country site displayed much higher readings than the other sites, however the only significant difference was in the one-year-old paddock. The large standard errors in the Cowboy Country sites suggested that the highly significant P-value reflected significant variation within sites, rather than between (Figure 4.10).

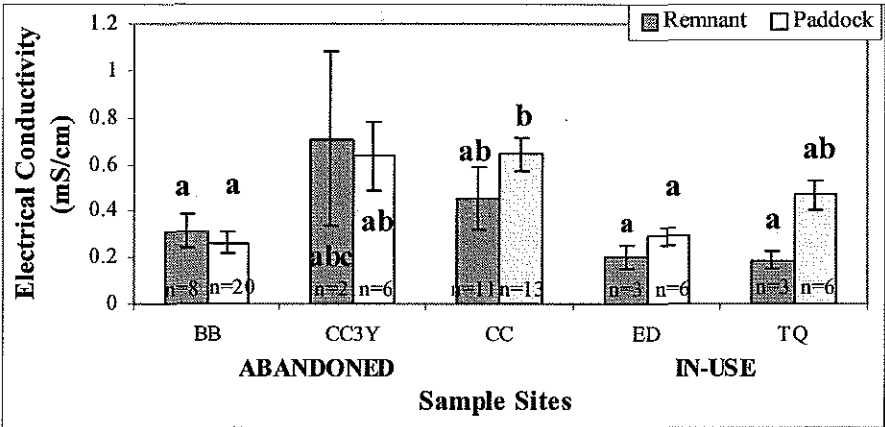


Figure 4.10: Electrical conductivity (mS/cm) in remnant and paddock soils across all study sites, by sample point ($F = 3.348$, $P = 0.002$). Tukey's-b post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

The CSBP laboratory analysis revealed significant differences between soil properties of the abandoned and currently farmed study sites. The soil texture analysis illustrated that in general, the surface soils of the remnant areas at each site contained more sand than the adjacent paddock soils (Figure 4.11). However the only significant difference occurred between the remnant and paddock soils of Cowboy Country (3yr-old) (Figure 4.11).

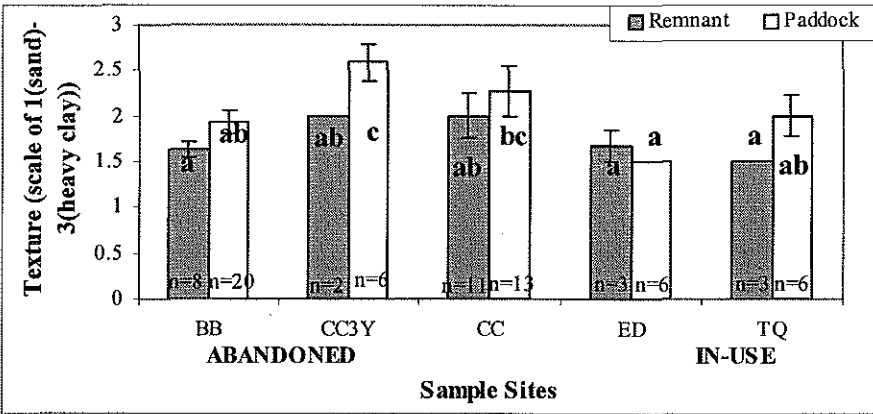


Figure 4.11: Soil texture between remnant and paddock areas at each study sites, by sample point mean ($F = 3.24$, $P = 0.003$). Games-Howell post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

The differences observed in nitrate concentrations between the paddock soils of the two farming sites and the three abandoned sites were very highly significant, with much higher concentrations observed in the soils currently under cultivation (Figure 4.12). Nitrate levels were consistently low in the remnant soils, as illustrated in Figure 4.12.

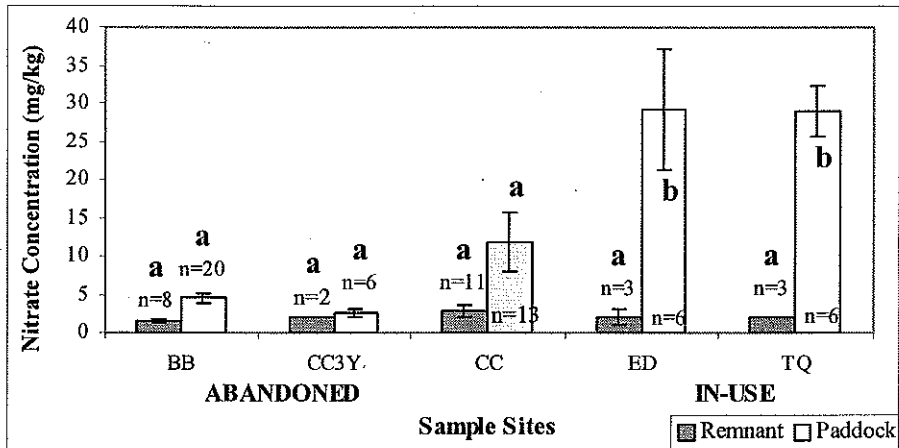


Figure 4.12: Nitrate concentration of remnant and paddock soils at each study site, by sample point mean ($F = 16.806$, $P = <0.001$). Games-Howell post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

No significant difference was observed in ammonium concentration of remnant and paddock soils across any of the study sites, however two general trends were evident (Figure 4.13). Ammonium concentrations were generally higher in the paddocks than the adjacent remnants at each study site and decreased as age since abandonment increased (Figure 4.13).

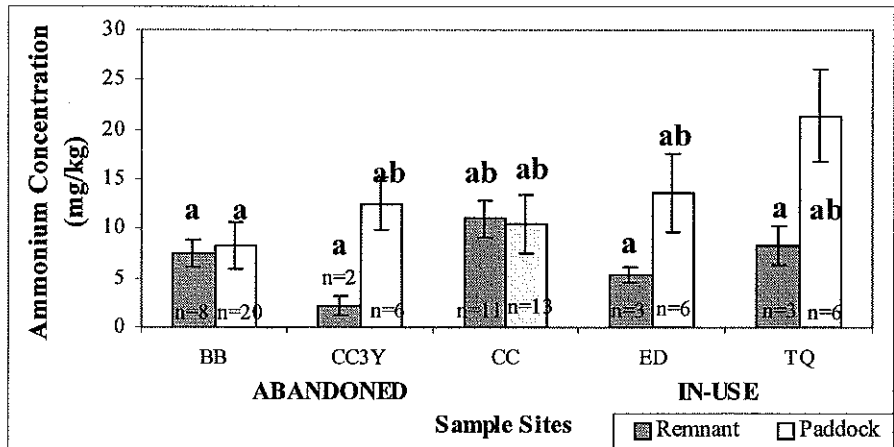


Figure 4.13: Mean ammonium concentration between remnant and paddock soils at each study site, by sample point ($F = 1.94$, $P = 0.061$). Tukey's-b post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

The analysis of available phosphorus content illustrated very highly significant difference between the paddock area at Torquata Ridge and the other sites (Figure 4.14). The trend across all sites was of greater phosphorus content in the paddocks than adjacent remnants, however concentrations of remnant and old-field soils at Bob's Bush were almost identical.

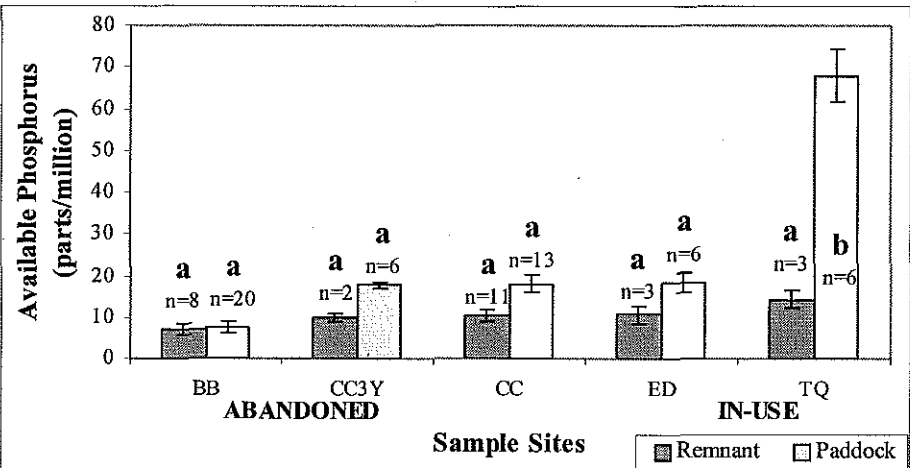


Figure 4.14: Mean available phosphorus content between remnant and paddock soils at each study site, by sample point (57.98, $P = <0.001$). Games-Howell post-hoc test results shown by letter code, where means of same letter not significantly different.

Organic carbon content was considerably higher in the remnant soils than the paddock soils at each study site, with significant differences observed at the three-year-old site and Bob's Bush (Figure 4.15). The highest organic carbon levels in both the paddock and remnant soils were observed at the two Cowboy Country sites (Figure 4.15).

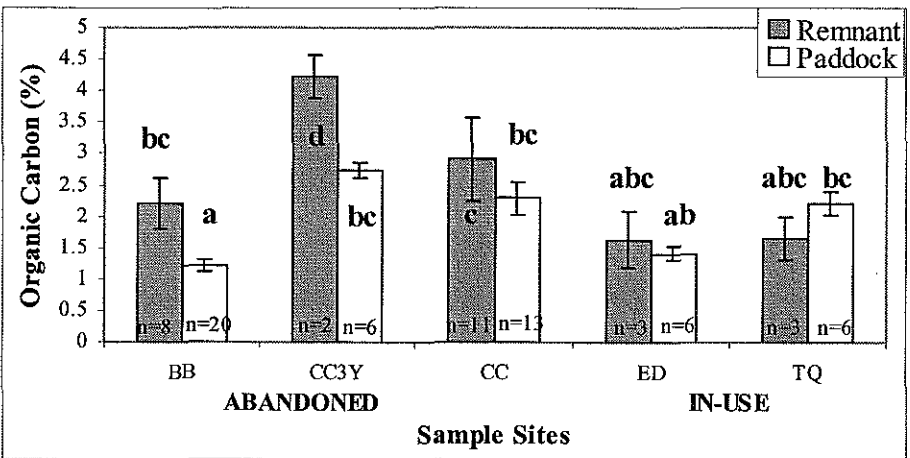


Figure 4.15: Mean organic carbon content between remnant and paddock soils at each study site, by sample point ($F = 7.952$, $P = <0.001$). Games-Howell post-hoc test results shown by letter code, where means sharing same letter are not significantly different.

4.3.2 CCA Results

The CCA ordination mirrored the trends observed in vegetation composition from the ordinations in Chapter 3, with strong division between remnant and paddock vegetation and the Bob's Bush paddocks displaying an intermediate composition. Compaction, nutrient concentration, organic matter content, proximity to remnant and time since abandonment were identified from the analysis as being strongly linked with vegetation composition.

The most striking distinction occurred between the paddock vegetation of the two currently farmed areas and the abandoned sites. This was strongly correlated with increased nutrient content on the farmed sites, in the form of ammonium, available phosphorus and nitrate (Figure 4.16). The trends in these three inorganic nutrient forms were closely aligned with the primary (horizontal) axis, indicating a strong correlation with the division between the floristics of the in-use and abandoned sites (Figure 4.16).

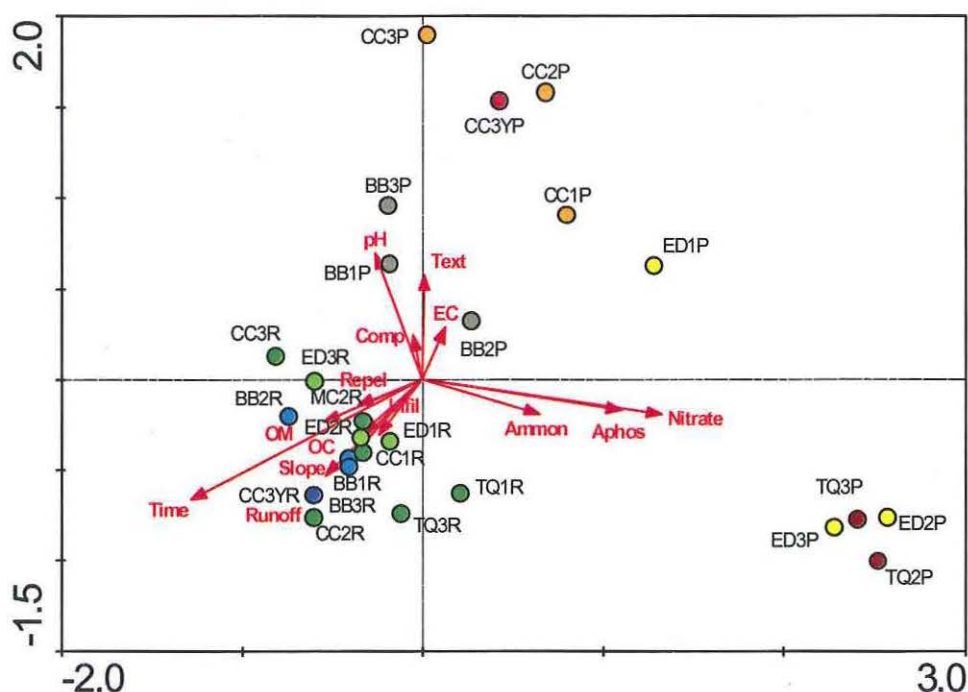


Figure 4.16: CCA bi-plot illustrating correlations between species composition and environmental factors in remnant and paddock areas across all study sites, by gradsect. Different colours delineate different gradsects: green-blue = remnants, brown- yellow = paddocks and letter codes as per Chapter 3, section 3.3.

The separation of the paddock areas of the abandoned sites from the remnant areas was correlated with pH, texture, electrical conductivity and compaction, however this correlation was not particularly strong (Figure 4.16). A correlation was observed between increasing time since abandonment and species composition and appeared to be the main separating factor between the remnant and paddock samples, with the site abandoned 26 years ago exhibiting more similarity to the remnants than those more recently abandoned (Figure 4.16). The clustering of the remnant samples at each study site was also strongly correlated with increased soil organic matter and organic carbon. A positive correlation also existed between increasing time since abandonment and runoff, infiltration and repellency, while nutrient content was negatively correlated with time (Figure 4.16).

When the analysis of vegetation patterns was broken down to investigate within individual abandoned study sites, the degree to which distance from remnant influenced species composition at each site became evident (Figure 4.17, 4.18 & 4.19). A strong correlation was observed between increasing distance from remnant vegetation and the species composition of paddock sample points within Bob's Bush, particularly for quadrats along Gradsect 2 (Figure 4.17). In addition, increasing compaction, nitrate concentration and pH were strongly correlated with species composition change in the paddocks at Bob's Bush along a gradient of increasing distance from remnant (Figure 4.17). Where nitrate, ammonium and phosphorus increased as distance from the remnant increased, organic matter and organic carbon decreased (Figure 4.17). This correlation again occurred along the first axis, indicating an important link between species composition and state of soil properties along a distance gradient.

The significant variation in species composition observed between the remnant vegetation of Gradsects 1 and 3 and Gradsect 2 at Bob's Bush was strongly correlated with increased soil organic matter, organic carbon, repellency and electrical conductivity at Gradsect 2, suggesting a significantly different environment (Figure 4.17). Increases in runoff, slope and infiltration characterised the remnant areas of Gradsects 1 and 3 (Figure 4.17). Another important distinction between Gradsects 1 and 3 and Gradsect 2 was that change in vegetation composition between remnant and old-field was very abrupt at Gradsect 2, whereas in Gradsects 1 and 3, more gradual changes were observed (Figure 4.17).

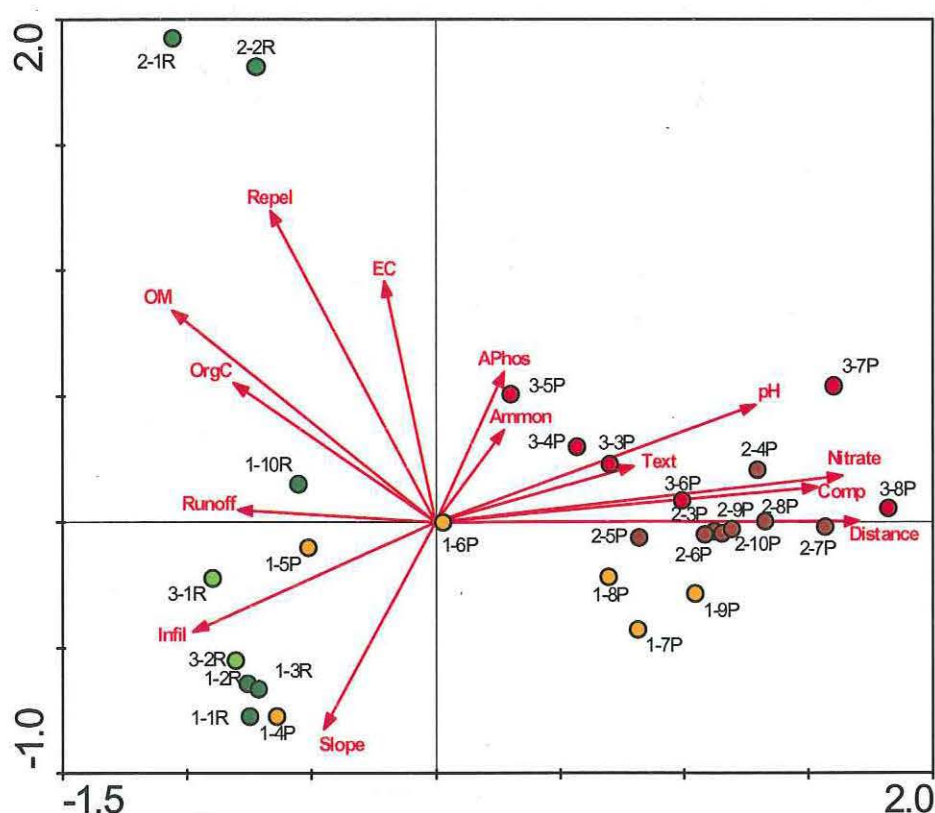


Figure 4.17: CCA bi-plot illustrating correlations between species composition and environmental factors in remnant and paddock areas at Bob's Bush, by sample point. Remnant colour code: dark green = Grad1, fluro green = Grad2, pale green = Grad3. Paddock colour code: Grad1 = yellow, Grad2 = brown, Grad3 = red. Letter codes as per Chapter 3, section 3.3 and numbers represent sample point.

The three-year-old site at Cowboy Country site exhibited strong distinction between remnant and paddock vegetation composition (Figure 4.18). The environmental factors linked with this dichotomy were increased slope and runoff and to a lesser degree, nitrate and ammonium content (Figure 4.18). The similarity between paddock sample points was very strong, with only sample point three revealing a distinct species composition (Figure 4.18). Soil texture was strongly correlated with species composition in the paddocks, illustrated as an increase in the clay portion of the soil (1=sand-3=heavy clay). As illustrated in Figure 4.11, the paddock soil at the three-year-old site revealed much higher clay content than that of the remnant.

Conversely, the two remnant sample points revealed significant variation in vegetation composition, as also illustrated in Chapter 3 (Figure 4.18). Differences in environmental factors were evident between the two sample points but as illustrated in Figure 4.18, the correlations were not particularly strong.

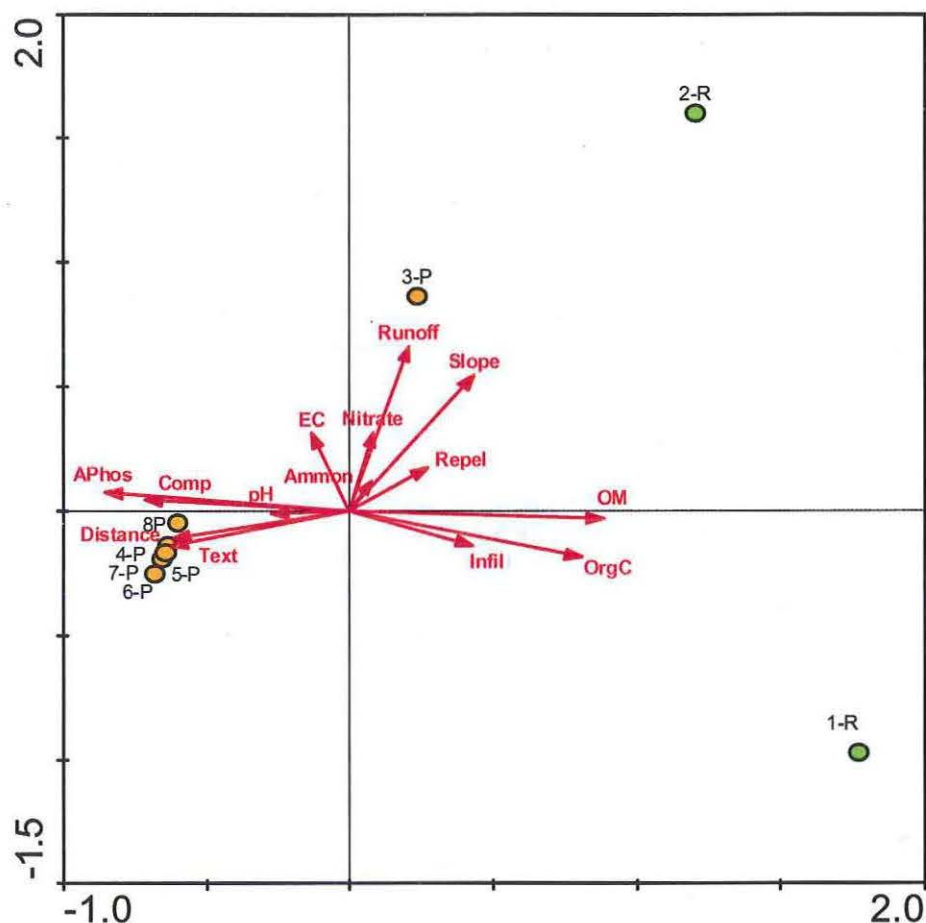


Figure 4.18: CCA Bi-plot illustrates correlations between species composition and environmental factors in remnant and paddock areas at Cowboy Country (3yr-old), by sample point. Colour code: pale green = remnant, yellow = paddocks. Letter codes as per Chapter 3, section 3.3 and numbers illustrate sample points.

Figure 4.19 illustrated a strong distinction between the species composition of the remnant and paddock areas at the one-year-old Cowboy Country site. In addition, significant variation was also observed between the species composition of remnant vegetation of

Gradsects 1 and 2 and Gradsect 3 (Figure 4.19). Increasing soil organic matter and organic carbon was strongly correlated with the species composition of Gradsect 1 and 2 and to a lesser extent, ammonium concentrations (Figure 4.19). Gradsect 3 on the other hand, was characterised by high rates of soil repellency to water (Figure 4.19).

The differences observed in species composition between the remnant and paddock sample points were linked predominantly to proximity to remnant, compaction, as well as nitrate and available phosphorus concentration (Figure 4.19). This pattern was very similar to that illustrated in Figure 4.17 for Bob's Bush. The species composition of paddock vegetation at Gradsect 1 was separated from Gradsect 2 and 3 by the bi-plot's first axis, along a gradient of increasing compaction, distance from remnant and nitrate at Gradsects 2 and 3 and increasing phosphorus and conductivity along Gradsect 1. The second (vertical) axis also caused separation, with increasing pH and clay content (texture) at Gradsects 2 and 3 and increasing ammonium and organic carbon at Gradsect 1 (Figure 4.19).

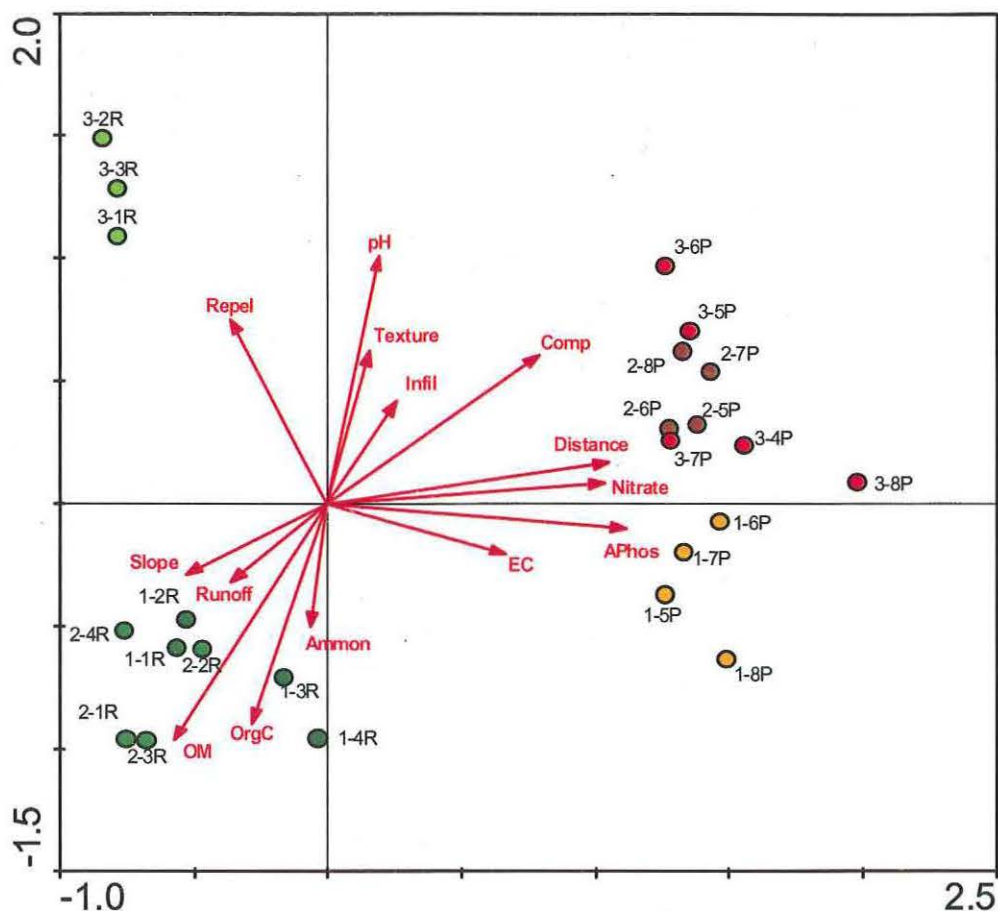


Figure 4.19: CCA bi-plot illustrating correlations between species composition and environmental factors in remnant and paddock areas at Cowboy Country (1yr-old), by sample point. Remnant colour code: dark green = Grad1, fluro green = Grad2, pale green = Grad3. Paddock colour code: yellow = Grad1, brown = Grad2, red = Grad3. Letter codes as in Chapter 3, section 3.3 and numbers represent sample point.

It was also observed that although increasing distance from remnant was strongly correlated with species composition in the paddocks at each abandoned site, the pattern illustrated at Bob's Bush differed to that of the two Cowboy Country sites. The pattern at Bob's Bush was generally indicative of a more gradual change along an increasing distance gradient, while at the one and two-year-old sites distance appeared simply to represent a division between remnant and paddock vegetation (Figure 4.17, 4.18 and 4.19).

4.4 DISCUSSION

It is evident from the analysis and description of soil characteristics that significant differences exist between the state of soil properties in the remnant and paddock areas at each site. It is also apparent that old-field soil properties have changed in relation to time since abandonment. The general trends observed between soil properties and floristic characteristics indicate that the state of soil properties may also influence the progression of old-field recovery.

Although it was not always illustrated in the significance of the results of the post-hoc tests, the CCA analysis and overall trends suggested that increasing age since abandonment and decreasing distance from remnant vegetation was correlated with a decrease in nutrient content, an increase in organic matter and organic carbon content, decrease in compaction and an increase in repellency, infiltration and runoff. These trends were subject to considerable variation and often the degree of within site variation for some of these variables meant that differences between sites were not detected.

The lack of significant difference in a number of areas may be attributable to the nature of the post-hoc test used to differentiate between means that did not display homogeneity of variance. The Games-Howell test is a conservative test that does not assume equal variance (Dytham, 2003). As such it may conceal significant differences between means and cause Type II error, in that the null hypothesis is false and should be rejected, but is accepted. Nonetheless where the Games-Howell test does show significant difference it is highly likely that there is one, therefore there is a small possibility of Type I error associated with it (Dytham, 2003).

The most notable differences between study sites were associated with the cycling of organic matter and nutrients, namely litter cover and depth, organic matter content, organic carbon content and nitrate, ammonium and phosphorus content. Not surprisingly, the two sites currently under cultivation exhibited much higher mineral nutrient levels than the three abandoned sites, particularly nitrate. The concentration at each of the remnants was very low, indicating that the natural soil state is one that is very low in available nitrogen,

an assumption supported by the work of Overheu (2001), who demonstrated naturally low levels of nitrogen in soils of the Jerramungup agricultural area. In addition, the heathland vegetation dominating the remnant vegetation at the study sites is adapted to very nutrient poor soils (Beard, 1982).

Nitrate and ammonium levels were much higher in the two sites currently under cultivation because of the application of inorganic fertilisers and the cultivation of a nitrogen 'fixing' legume species, *Trifolium subterraneum* as a pasture species (Hussey, Keighery, Cousens, Dodd & Lloyd, 1997). Leguminous species are able to convert atmospheric nitrogen to inorganic forms available to plants, namely nitrate and ammonium, because of a symbiotic relationship with *Rhizobium* bacteria that grow on the roots (Hurditch, 1994).

The inorganic nitrogen component of the paddock soil generally decreased with increasing age since abandonment, indicating a return to the cycling processes occurring in nutrient poor soils over time. It also may indicate increased vegetative cover, as in nutrient poor soils in semi-arid areas, any nutrients made available to plants are very quickly sequestered (Escudero, Garrido, Matias & del Arco, 1988). Relative proportions of nitrate to ammonium were similar at each site, but the three-year-old site contained considerably higher levels of ammonium than nitrate. Nitrate is a highly soluble compound and three years of no inorganic inputs may have resulted in significant leaching and again, plant uptake may well be high due to the extensive cover of large, fast growing, perennial shrubs at this site (Rendig & Taylor, 1989). Conversely, the ammonium levels at the three-year-old site were considerably higher than at the one-year-old and 26-year-old sites. This could be attributable to the high cover of *Acacia* species, known to be able to 'fix' nitrogen. Nitrate levels at the one-year-old site were still relatively high, suggesting persistent residues from cropping. These are expected to decrease substantially over the next 2-3 years, as plant cover increases and leaching continues with no inputs to the system by way of breakdown and mineralisation of organic matter (Escudero *et al.*, 1988).

The carbon : nitrogen (C:N) ratio of the soil has a very strong regulatory influence in the release of mineralized nitrogen (Rendig & Taylor, 1989). A steady state is considered to be a C:N range from 9:1-12:1, while litter rich in carbon will conversely be relatively poor in

nitrogen (Specht & Specht, 1999). The carbon/nitrogen ratios of the remnant soils at each study site appeared to be high, in that they contained a lot of carbon and little soluble nitrogen. The paddock ratios were very low at the currently farmed sites, with high nitrogen levels in comparison to organic carbon. This is characteristic of agricultural soils, as the removal of vegetation also removes the source of soil carbon and artificial fertilisers are the main source of nutrient input (Lefroy, Hobbs & Scheltema, 1993). Nitrate levels were much higher in the old-field at Bob's Bush than in adjacent remnant. Conversely, organic matter content was much lower and carbon content was significantly lower than the remnant and the two other abandoned sites. Approximately 97-99% of all nitrogen in the soil is bound to the organic fraction (Bremner, 1996). The breakdown and mineralisation of this organic nitrogen releases it slowly from the organic fraction, making it available to plants (Bremner, 1996). In a nutrient poor system such as that of south-coast mallee-heath vegetation, this breakdown and release occurs very slowly and the carbon to nitrogen ratio is high (Beard, 1982). The ratio of carbon to mineral nitrogen at Bob's Bush suggests that natural decomposition and cycling processes are occurring very slowly.

A lack of organic matter is often attributed to a lack of vegetation cover and hence, litterfall (Kimmins, 1997). However this does not appear to be the case in the old-field soils at Bob's Bush, as litter cover and depth was comparable with the two other abandoned sites and bare soil cover was considerably lower. This disparity between litter cover and the soil organic fraction suggests that the processes facilitating the breakdown of surface litter may be inhibited at Bob's Bush. This has long term implications for the continued cycling and mineralisation of soil organic matter to provide available nutrients for recovering vegetation (Kimmins, 1997). A lack of organic matter breakdown in the presence of litter cover can often be attributed to a lack of soil biota (Giller, 1996). Soil invertebrates such as mites and Collembola (springtails) are responsible for the breakdown and transport of organic matter in the soil substrate and bacteria and fungi facilitate the mineralisation of organic matter (Giller, 1996). A paucity of soil diversity is often characteristic of agricultural soils, due to physical and chemical alterations to the soil substrate (Potter & Meyer, 1990).

The dominant soils of the study region are nutrient poor and require fertiliser, particularly in the form of super-phosphate, in order to maintain cropping and pasture (Overheu, 2003; Overheu, 1996). The very high available phosphorus concentration observed at Torquata Ridge arose because the farmer had recently fertilised, using superphosphate (I. Macmillan, pers. comm., June, 2004). The other farming site exhibited very similar levels to the one and three-year-old sites, while concentrations were very low at Bob's Bush. Phosphorus leaching is a significant issue throughout the south-coast, because of the predominance of sandy soils and intensive drainage (Runge & van Gool, 1999). In addition, phosphorus rapidly forms insoluble compounds when applied to soil, binding to ions such as calcium, magnesium, aluminium and iron and thereby forming highly insoluble precipitates (Kuo, 1996). This makes phosphorus unavailable to plants and may have significant impact in soils with high content of such ions (Kuo, 1996).

The cracking clay soils observed in the low-lying areas at Bob's Bush are high in aluminium (Department of Agriculture, 2003), which may also account for the very low mean available phosphorus levels observed at that site. The application of bauxite mining residue ('red mud') has been suggested by Summers, Guise and Smirk (1993) as a potential phosphorus immobiliser in sandy soils, as it is high in iron and aluminium that phosphorus binds particularly well to. However in a landscape where vegetation is already highly susceptible to the root pathogen *P. cinnamomi* (Beard, 1990) the feasibility of introducing residue from the contaminated jarrah region requires careful consideration.

There was no significant difference in cryptogam cover between the study sites, however the fact that cryptogams were present in the remnants and old-fields but not the paddocks currently under cultivation has implications for the breakdown of organic matter and nutrient cycling. The term 'cryptogam' encompasses algae, fungi, mosses, lichens and liverworts (Tongway & Hindley, 1995). These plants are often early colonisers of recovering soils and are positive indicators of surface stability, as they do not grow on unstable soils (Tongway, 1994). They are important to the decomposition and mineralisation of nitrogen and carbon, they aid in the prevention of surface soil erosion and encourage more rapid infiltration of moisture (Tongway, 1994).

Surface compaction in the old-fields at Bob's Bush was significantly higher than that of the other sites, despite its age since abandonment. As it was also significantly more compacted than the adjacent remnant illustrates that the differences observed between study sites were not simply due to natural variation in soils. Heavy machinery, particularly harvesters and tractors, and grazing of domestic stock are the principle causes of surface compaction in agricultural soils (Runge & van Gool, 1999; Yates, Norton & Hobbs, 2000). Compaction is often attributed to loss of organic matter, leading to soil structure deterioration (Tongway, 1994). In turn, compaction prevents the breakdown of organic matter, as loss of soil pores inhibits the movement of soil biota responsible for decomposition (Potter & Meyer, 1990).

Soil that loses its structure is prone to surface crusting, as a result of rain splash (Needham, Moore & Scholz, 1998). Surface crusting was commonly observed throughout the old-fields at Bob's Bush. Surface compaction and loss of soil structure often lead to slower infiltration, which in turn prevents moisture from reaching the deeper soil profile and stimulating seed germination and the subsequent emergence of seedlings (Runge & van Gool, 1999). Differences in compaction levels are also attributable to differences in soil type, in that soils of small, uniform particle size are more susceptible (Needham *et al.*, 1998). In the low lying areas of Bob's Bush where clay soils were noted compaction was very high, whereas soils of the upper slopes had a greater sand component and were less so. This variation in compaction is illustrated by very high standard error in Figure 4.6.

Compaction in the Bob's Bush old-fields appears to have an important influence on vegetation recovery. An abrupt change in compaction between the remnant and old-field correlates with an abrupt drop in diversity and change in species composition at Gradsect 2. Compaction is also linked to a major floristic gradient across the remnant/old-field transition, particularly at Gradsect 3. This pattern suggests an increase in compaction over increasing distance from the remnant may have a strong influence on change in species composition (Figure 4.17). Compaction may be preventing colonisation and establishment of deep-rooted plant species at greater distances from the remnant vegetation at Bob's Bush, as it prevents the penetration of the soil surface by young seedling roots (Needham *et al.*, 1998). The grass species *Austrodanthonia* has shallow roots that can take advantage of surface soil moisture and so is likely to be less influenced by compaction, as evidenced by

its dominance in the old-fields (Epp & Aarson, 1988). A similar trend in increasing surface compaction with distance was observed at the one and three-year-old sites, which may have implications for future vegetation recovery.

Surface compaction in the old-fields of the two younger sites was not as high as in the 26-year-old site, however a 'plough pan' was noted approximately 10cm beneath the surface at the one-year-old site. This form of shallow subsurface compaction results from ongoing tillage of the soil to a constant depth for cropping (Runge & van Gool, 1999). It impacts on root elongation and rooting depth of plants, which in turn impacts on their ability to take up moisture and mobile nutrients like nitrate (Runge & van Gool, 1999). This plough pan may have implications for the longevity of deep-rooted plants that colonise the old-fields of this site in the future.

Repellency was generally higher in the remnants than the adjacent paddocks at each study site. These differences in repellency correlated with greater organic matter content and sandier texture of the soil in the remnants. Water repellence is caused by the presence of hydrophobic compounds that arise from the breakdown of organic matter and coat soil particles (Runge & van Gool, 1999). Organic compounds arising from the decomposition of litterfall from *Eucalyptus* and other Myrtaceae species common to the study sites are particularly repellent, as they contain oils such as cineole that have hydrophobic properties (Markham & Nobel, 1989). Sandy soils are often associated with increased repellency, as they consist of particles of lower surface area that require less hydrophobic compounds to render them water repellent (Overheu, 1996). The disparity between the sand /clay ratio of the predominantly duplex remnant and old-field soils may be a result of past tillage in the old-fields, which facilitated the merging of the sandy surface soil with the clay or clay/loam underneath (Runge & van Gool, 1999).

Under the classification of repellency using the timing method by the Department for Sustainable Resources (1999), 1-10 seconds means that soil has very low repellency, 10-50 seconds means low repellency (Table 4.1). Under this classification, the soils within both the remnants and old-fields at each study site had low to very low repellence. This suggests that repellency was not a particularly important influence of vegetation recovery.

No significant variation in pH or electrical conductivity existed between the remnant and old-field soils at each of the study sites, indicating basically similar soils. Electrical conductivity tended to be higher in the soils of the one and three-year-old sites, however considerable variation in concentration occurred. Links between pH and conductivity and vegetation composition were generally weak, suggesting that they are not influencing the progression of old-field vegetation recovery at the abandoned sites to a large degree.

Slope was generally similar between remnant and old-field areas at each study site, however at the two Cowboy Country sites there was some deviation and this appeared to be linked to change in vegetation composition. This was particularly evident at the three-year-old site. The change in slope corresponded to a change in floristic composition. The mallee heath dominating the summit of the spengolite breakaway changed abruptly to a stand of *Eucalyptus platypus* (Moort) at the base of the breakaway. Differences in environmental factors were evident between the two remnant sample points but as illustrated in Figure 4.18, the trends were not particularly strong. Therefore it may not be feasible to compare the success of old-field recovery to remnant vegetation in these areas, as the vegetation naturally inhabiting valley as apposed to crest areas may differ.

Runoff was higher and infiltration slower in the remnant areas than in the corresponding paddock areas. This is possibly related to cover of understorey/groundcover species. The remnant soil surfaces at each study site were generally characterised by good litter cover, but understorey vegetation was often sparse and water simply ran beneath the litter. In the paddocks however, the thick *Austrodanthonia* growth was effectively preventing excessive runoff and facilitating more rapid infiltration by creating a physical barrier to water movement. This indicates that even though regeneration of native species may not be occurring at a rapid rate, advantages exist with regard to retaining shallow rooted perennial vegetation cover such as *Austrodanthonia* in recovering old-fields. Moisture is being captured and the surface soil is being protected from wind and water erosion by this vegetation. This is particularly important for the sandier soils occurring throughout the study region, as they are highly susceptible to wind erosion (Goddard *et al.*, 1981).

Microtopography was an important consideration in the analysis and description of the interactions between soil and vegetation characteristics, despite the fact that it wasn't measured quantitatively. Microtopography is an assessment of the degree of soil surface 'roughness' that facilitates the capture of moisture, organic matter and seed (Tongway & Hindley, 1995). The strongest evidence of microtopography influencing vegetation recovery on old-fields occurred at the one-year-old site. Clear rip lines remaining from past cropping were observed at Gradsect 1 but not at Gradsect 2 or 3. In addition, the diversity observed at Gradsect 1 was also higher than the other two gradsects and the species composition was dissimilar. The microtopographical features observed at Gradsect 1 may have facilitated greater diversity of colonisation than Gradsects 2 and 3, as furrows relict of past ripping are capable of capturing moisture, organic matter and seed.

Some of the differences in soil properties and vegetation characteristics observed between and within study sites may be attributed to natural landscape variability in vegetation and soils, rather than recovery from degrading processes. The soils at Cowboy Country are influenced by spongolite/siltstone weathering, while Bob's Bush is more influenced by granite and dolerite. The upper slopes of both sites are shallow to deep sandy duplex, often with a considerable gravel component, while the low lying areas contained a greater clay portion. The influence of slope on vegetation composition within the three-year-old Cowboy Country site demonstrates the potential influence of landscape variability. The differences in structural complexity between the vegetation at Bob's Bush and Cowboy Country described in Chapter 3 may also be a result of landscape variability in vegetation, rather than a feature of recovery and succession.

The cracking clay soil observed in areas of Bob's Bush is best described in the Department of Agriculture (2003) as a red 'vertisol' hard cracking clay. This soil type is susceptible to loss of soil structure, is high in aluminium, has low pH, a high water storage capacity, yet low water availability (Department of Agriculture, 2003). This soil develops from the deposition of weathered dolerite material and a number of dolerite outcrops were observed at Bob's Bush. This combination of characteristics has established it being hostile to plant growth (Department of Agriculture, 2003). In addition, below average direct seeding results have been observed on soils of this description (Jack Mercer *pers. comm.*, 2004). The

inhibitory nature of this soil to plant growth may be an important factor in the relatively slow and patchy regeneration observed at Bob's Bush.

On the other hand, the soils at Cowboy Country are derived predominantly from spongolite and are characteristically grey shallow sandy duplex (Overheu, 1996). The risk of surface soil acidification is high in these soils, while salinisation of the subsoil is possible on lower valley slopes. The sandy surface soil is often repellent and is prone to wind erosion (Overheu, 1996). In general however, these soils are relatively conducive to plant growth. Therefore the higher salt concentration of these soils may be attributed to soil type.

4.5 CONCLUSIONS

It is evident from the results of the soil analysis and description at each of the study sites that trends between time and the state of certain soil properties are important. The most significant of these was the shift in nutrient status in the paddocks from a predominantly inorganic, rapidly cycling and wasteful system dependant on artificial inputs of inorganic fertiliser in soils currently under cultivation to a system derived from the slow breakdown of organic material in the 26-year-old site. When cross-referenced with the nutrient status of remnant soils it appears that over increasing time since abandonment, more nutrient cycling processes emerge, however the proportionately low organic matter and carbon content at Bob's Bush requires consideration during revegetation.

Trends were apparent between increasing distance from the edge of remnant vegetation and changes in soil characteristics, predominantly increasing compaction, increasing inorganic nutrient concentrations and decreasing organic matter and carbon content. These changes correlated with changes in the recovery of vegetation composition on old-fields. Furthermore, some differences in vegetation progression were attributable to landscape variation in topography, soils and vegetation. However in order to establish the degree to which these factors are influencing recovery, if they are at all, further study is required.

CHAPTER 5: SYNTHESIS

5.1 FLORISTIC CHARACTERISTICS AND SOIL PARAMETERS

From the analysis of floristic characteristics of old-fields of a broad age range, it was established that vegetation complexes comparable to the original vegetation (as represented by remnant vegetation) are recovering on abandoned agricultural land in the Fitzgerald Biosphere. However considerable dissimilarity between old-field and remnant vegetation still exists, even at the site abandoned 26 years ago. The rate at which recovery is occurring is not rapid and is influenced significantly by time since abandonment and to a lesser degree the proximity of healthy native vegetation remnants of substantial size.

One of the aims of this research was to explore patterns and trends in soil properties that are often impacted on by agricultural practice and to establish potential correlations and associations between them and vegetation recovery on old-fields. The analysis of pattern in soil properties using CCA illustrated that associations exist between soil compaction, nutrient and organic matter content, vegetation composition, time since abandonment and proximity to remnant vegetation. A comparison of paddocks currently under cultivation and relatively undisturbed remnant areas indicated that the above soil factors have been significantly modified as a result of agricultural practice and need to recover over time in order for the native vegetation to recover on old-fields.

This research revealed that trends in environmental factors are not easily separated from an analysis of the trends in floristic characteristics when analysing and describing old-field recovery. It also revealed the importance of establishing the extent to which soil properties modified by agricultural practice influence recovery, or whether differences are simply attributable to landscape variation between sites.

5.2 KEY BARRIERS TO NATIVE VEGETATION RECOVERY

Time was identified as the most important determinant in recovery. Each of the floristic characteristics and soil parameters was considered in the context of time since

abandonment, often revealing strong trends. Time is required for the impacts of agricultural activities on soil condition to repair, for the colonisation and establishment of seedlings on old-fields and for the germination of seed stored in the soil.

Increasing distance from areas of remnant vegetation was a recognisable factor in revegetation progression with regards to diversity and composition. Diversity increased and composition became more similar in old-field vegetation with increasing proximity to remnant vegetation, but the level of similarity between the two was still generally very low. It appeared that soil seed store played a more important role in the initial stages of recovery than dispersal from remnants. The results of this research also indicate that the role of fire in the regeneration of native vegetation in this landscape requires consideration. If the species dominating the remnant vegetation are unable or less likely to be able to colonise the old-fields without the stimulus of fire some treatment may be required, either by way of prescribed burning, using treated seed for revegetation via direct seeding or the application of smoke water directly onto old-fields to stimulate germination. In either case, detailed study of the impacts and importance of fire for the vegetation of the region is required.

In the case of Bob's Bush, 26-30 years does not appear to have been sufficient time to repair soil structural characteristics like compaction and physiochemical characteristics like the breakdown of organic matter to provide inorganic nutrients for plant uptake. Addressing this lack of progression may involve an approach similar to the ecological thresholds model for degraded wildlands described in Whisenant (1999) (Figure 5.1).

As described in Whisenant (1999), this ecological thresholds model was developed with the objective of removing impediments to recovery of degraded wildlands using minimum intervention methods, thereby initiating self repair processes and the reestablishment of ecosystem function. Ecosystems have certain thresholds with regards to the ability to self repair following disturbance. Once an ecosystem is pushed beyond a particular threshold the management required to restore that ecosystem to a healthy state, or to facilitate its natural recovery becomes much more intensive (Whisenant, 1999).

The built in repair mechanisms of ecosystems can overcome different disturbance levels to a certain degree, but when a critical threshold is passed the ability of an ecosystem to self repair rapidly decreases (Whisenant, 1999). Figure 5.1 represents the stepwise degradation thresholds model described by Whisenant (1999). Steps 0 and 1 represent situations in which minimal manipulation by way of improved vegetation management is required for an ecosystem to self repair, as primary processes such as nutrient cycling and organic matter decomposition are still fully functional (Whisenant, 1999). Step 2 represents a situation in which the threshold controlled by biotic interactions has been exceeded and vegetation manipulation is required in order to stimulate self repair (Whisenant, 1999). Steps 4 and 5 represent an ecosystem that has been disturbed to such a degree that the threshold controlled by abiotic limitations has been exceeded and primary processes are non-functional, or functioning poorly. Manipulation of the physical environment is required in order for vegetation to recover (Whisenant, 1999). In the context of this model, it would appear that all three of the abandoned properties involved in this research require level 4 intervention in order for vegetation to recover, as they have all undergone disturbance to the abiotic environment.

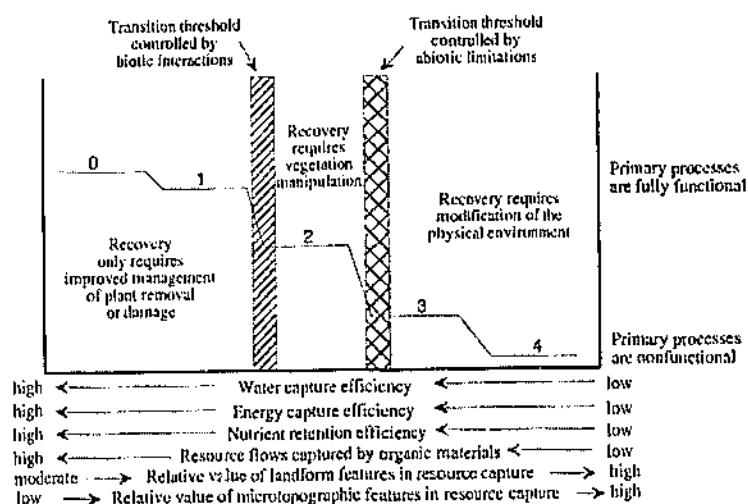


Figure 5.1: Stepwise ecological thresholds model for applications in wildland vegetation repair (Whisenant, 1999).

5.2.1 Implications for Management

Management of Abandoned Agricultural Areas

With the system devised by Whisenant (1999) in mind, the implications for management of abandoned agricultural areas will vary in conjunction with the extent of degradation to biotic and abiotic factors. The level of ecosystem degradation and the level of intervention required to facilitate recovery needs to be identified. Some areas may only require abandonment in order to recover, whereas some properties will be severely degraded. Prior to abandonment these properties have undergone clearing of native vegetation and intensive cropping and grazing that has significant impacts on soil properties, so it is likely that most will require level 4 intervention.

For example, level 4 intervention at the Bob's Bush old-fields will need to address compaction of the soil and the lack of organic matter breakdown. In order to address these issues surface ripping and mulching could be applied. Ripping creates microtopographical feature that may facilitate the capture of seed, organic matter and moisture (Whisenant, 1999). Mulching is a considerable initial expense, however it reduces follow up costs particularly associated with weed eradication (Whisenant, 1999). It addresses the issues of soil surface protection, while creating organic matter inputs which may facilitate the cycling of organic matter and nutrients, thereby improving soil structure and enhancing moisture retention which are important in encouraging the activity of soil biota (Milton *et al.*, 1994). It is anticipated that this may stimulate the natural cycling of organic matter, which in turn may encourage an increase in vegetation cover.

Management of Remnants

In order to enhance the potential for old-field recovery to occur at an adequate rate, the health of remnants needs to be sustained. Connectedness is an important factor for consideration, as is the establishment and maintenance of considerable sized remnants. As a potential source of seed, organic matter and soil biota beneficial to soil processes and recovery of ecosystem function in old-fields, remnants need to be of high quality. From what has been observed throughout this research, weed invasion in remnants does not

present a serious management issue in this area of Fitzgerald Biosphere. As long as this relative absence of exotic species can be maintained, remnant vegetation management will be relatively straightforward.

1. **Fire** Stimulation of seed germination and dispersal also requires consideration. That is widely farmed, contains reserves of international importance and many rare and endangered species such as the mallee-fowl, the feasibility of controlled burns is questionable. If this were carried out, it would have to occur following extensive study into the required fire regimes of key plant species and tolerances of species that do not require fire to regenerate. The propagation of seed of fire dependant species using treatment such as smoke water may be a more feasible option. In this case, healthy remnant vegetation is important for viable seed collection.

5.3 POTENTIAL FOR NATURAL REGENERATION IN REVEGETATION

From the results of this research, it was established that old-field recovery has potential as a revegetation technique for organisations such as Gondwana Link, under certain conditions. The nature of this process is an inherently slow one. With time a chief barrier to old-field recovery, it should not be employed as a remediation method where rapid results are required, as it would simply occur too slowly.

In addition, as proximity to remnant vegetation appears to influence the progression of old-field recovery to a degree, as the source of some recruitment and dispersal, it may not be an effective means of revegetation of large areas isolated from healthy remnants. Further study is required to establish which species are capable of recruiting readily from remnants and which species may require assistance. However as observed at Bob's Bush and Cowboy Country, soil seed store also plays a very important role in native species establishment on old-fields. Therefore remnants may not be required close by if the soil seed store is intact.

It may prove beneficial to leave old-fields for 2-3 years following abandonment to establish the potential for soil seed germination, remnant seed dispersal or both to facilitate the colonisation of old-fields. In many areas of the Fitzgerald Biosphere prone to wind erosion,

the initial objective of regeneration may be soil stabilisation rather than high levels of regeneration. The benefits of *Austrodanthonia* alone colonizing old-fields in the Fitzgerald Biosphere have been illustrated in Chapter 4. In addition, the natural decrease in mineral nutrient content with increasing time since abandonment observed in the results may be beneficial given that most native species are adapted to low nutrient levels, whereas exotic species often take advantage of nutrient rich soils.

To conclude that this method may be introduced as a replacement of direct seeding and planting techniques is untrue and was not the aim of this project. Its most efficient use would be in conjunction with other revegetation techniques, such as direct seeding or planting, particularly in very disturbed areas where soil seed may be diminished and remnant vegetation degraded. It must also be acknowledged here that this research is very site specific and the results and recommendations from the results may not be applicable throughout the Fitzgerald Biosphere. The high landscape variability of soils and vegetation in the Biosphere will have implications for the implementation of old-field regeneration as a revegetation technique.

Despite these potential limitations, the potential benefits to organisation such as Gondwana Link of integrating this approach into current revegetation plans are significant. Aside from reducing costs and increasing efficiency of operations, this technique allows those carrying out revegetation works to observe the process of native vegetation recovery and gain a more in depth understanding of the native vegetation associations inhabiting the area.

5.4 RECOMMENDATIONS

1. That any site manipulation implemented by Gondwana Link as part of revegetation be postponed following abandonment of a particular property or area, to establish the potential of vegetation to recover naturally/with no human intervention.
2. Further study into potential biological barriers identified is required prior to implementation in revegetation, specifically fire as a seed germination trigger, soil seed availability and viability and dispersal mechanisms of seed of remnant species.
3. That old-field recovery be implemented as a revegetation technique in areas where healthy remnant vegetation of substantial size is available as a source of seed.
4. Further study into specific soil characteristics correlated with the progression of old-field recovery is required prior to implementation of revegetation, particularly compaction, loss of soil structure, litter and organic matter content and nutrient cycling processes.
5. In the event that site preparation is required, by way of biological or physical manipulation, an ecological thresholds model such as that of Whisenant (1999) should be employed to ensure efficiency of site manipulation.

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APPENDIX

Table A.1: Species identified in the field, along with classifications of individual species according to different functional groups.

Sp. Code	Species Name	Common Name	Raunk (code)	Exotic/ Native	Annual/ Perennial
1	<i>Melaleuca sp.1</i>		N	Native	Perennial
2	<i>Melaleuca sp.2</i>		N	Native	Perennial
3	<i>Melaleuca sp.3</i>		N	Native	Perennial
4	<i>Verticordia sp.1</i>		Ch	Native	Perennial
5	<i>Gastrolobium parviflorum</i>	Box Poison	N	Native	Perennial
6	<i>Eucalyptus pluricaulis</i>		M	Native	Perennial
7	<i>Hakea biforcata</i>		N	Native	Perennial
8	<i>Melaleuca sp.4</i>		M	Native	Perennial
9	<i>Borya constricta</i>	Pincushion	Ch	Native	Perennial
10	<i>Lepidosperma sp.1</i>		Hm	Native	Perennial
11	<i>Melaleuca hamata</i>	Broombush	N	Native	Perennial
12	<i>Unknown sp.1</i>		Ch	Native	Perennial
13	<i>Eucalyptus floctoniae</i>		M	Native	Perennial
14	<i>Grevillea oligantha</i>		N	Native	Perennial
15	<i>Grevillea patentiloba</i>		N	Native	Perennial
16	<i>Lepidosperma sp.2</i>		Hm	Native	Perennial
17	<i>Davesia retrorsa</i>		N	Native	Perennial
18	<i>Isopogon axillaris</i>		N	Native	Perennial
19	<i>Eucalyptus conglobata</i>	Port Lincoln Mallee	M	Native	Perennial
20	<i>Hakea commutata</i>		N	Native	Perennial
21	<i>Unknown sp.2</i>		Hm	Native	Perennial
22	<i>Verticordia sp.2</i>		Ch	Native	Perennial
23	<i>Eucalyptus aff. foecunda</i>		M	Native	Perennial
24	<i>Melaleuca undulata</i>	Hidden Honeymyrtle	N	Native	Perennial
25	<i>Banksia media</i>	Southern Plains Banksia	M	Native	Perennial
26	<i>Unknown sp.3</i>		C	Native	Perennial
27	<i>Austrodanthonia sp.1</i>	Wallaby Grass sp.	Hm	Native	Perennial
28	<i>Grevillea pectinata</i>	Comb-Leaved Grevillea	N	Native	Perennial
29	<i>Goodenia scapigera</i>	White Goodenia	Ch	Native	Perennial
30	<i>Leucopogon sp.1</i>		N	Native	Perennial
31	<i>Boronla sp.1</i>		N	Native	Perennial
32	<i>Phebalium sp.1</i>		M	Native	Perennial
33	<i>Coopermookia polygalaceae</i>		N	Native	Perennial
34	<i>Davesia sp.1</i>		N	Native	Perennial
35	<i>Astartea sp.1</i>		Ch	Native	Perennial
36	<i>Acacia drummondii</i>		Ch	Native	Perennial
37	<i>Epacridaceae conostephium</i>		N	Native	Perennial
38	<i>Acacia sp.1</i>		Ch	Native	Perennial
39	<i>Trymalium sp.1</i>		N	Native	Perennial
40	<i>Davesia sp.2</i>		M	Native	Perennial
41	<i>Hibbertia gracilipes</i>	Buttercups	Ch	Native	Perennial

42	<i>Acacia glaucoptera</i>	Flat Wattle	Ch	Native	Perennial
43	<i>Acacia cyclops</i>	Red-Eyed Wattle	M	Native	Perennial
44	<i>Eucalyptus platypus</i>	Round-leaved Moort	M	Native	Perennial
45	<i>Melaleuca</i> sp.5 (<i>carticularis</i> group)		N	Native	Perennial
46	<i>Exocarpus aphylla</i>		N	Native	Perennial
47	<i>Eucalyptus recondita</i>		M	Native	Perennial
48	<i>Melaleuca</i> sp.6		N	Native	Perennial
49	<i>Eucalyptus celastroides</i> (<i>sub sp. virella</i>)		M	Native	Perennial
50	<i>Thryptomene</i> sp.1		N	Native	Perennial
51	<i>Melaleuca</i> sp.7		N	Native	Perennial
52	<i>Eucalyptus annulata</i>	Open-Fruited Mallee	M	Native	Perennial
53	<i>Leptospermum</i> sp.1		N	Native	Perennial
54	<i>Boronia</i> sp.2		N	Native	Perennial
55	<i>Melaleuca</i> sp.8		N	Native	Perennial
56	<i>Grevillea nudiflora</i>	Trailing Grevillea	N	Native	Perennial
57	<i>Asteraceae</i> sp.1		Th	Exotic	Annual
58	<i>Melaleuca</i> sp.9		N	Native	Perennial
59	<i>Acacia bidentata</i>		Ch	Native	Perennial
60	<i>Verticordia</i> sp.3		Ch	Native	Perennial
61	<i>Myrtaceae</i> sp.1		N	Native	Perennial
62	<i>Mvelenbeckia adpressa</i>		Ch	Native	Perennial
63	<i>Acacia</i> sp.2		Ch	Native	Perennial
64	<i>Allocasuarina huegeliana</i>	Rock Oak	M	Native	Perennial
65	<i>Solanum nigrum</i>	Black-berry Nightshade	N	Exotic	Perennial
66	<i>Maireana brevifolia</i>	Small-leaved Bluebush	Ch	Native	Perennial
67	<i>Calothamnus gracilis</i>		N	Native	Perennial
68	<i>Acacia</i> sp.3		N	Native	Perennial
69	<i>Unknown</i> sp.4		N	Native	Perennial
70	<i>Davesia</i> sp.3		N	Native	Perennial
71	<i>Unknown</i> sp.5		Hm	Native	Perennial
72	<i>Verticordia mitchelliana</i>	Rapier Featherflower	N	Native	Perennial
73	<i>Eucalyptus phaenophylla</i>		M	Native	Perennial
74	<i>Leucopogon</i> sp.3		N	Native	Perennial
75	<i>Unknown</i> sp.6		N	Native	Perennial
76	<i>Neuranche allopecturodiaea</i>	Mulga Grass	Hm	Native	Perennial
77	<i>Chordifex</i> sp.1		Hm	Native	Perennial
78	<i>Billardiarea</i> sp.1		Ch	Native	Perennial
79	<i>Unknown</i> sp.7		N	Native	Perennial
80	<i>Callytris</i> sp.1		M	Native	Perennial
81	<i>Astratoma epacridis</i>		N	Native	Perennial
82	<i>Boronia incomata</i>	Pink Boronia	N	Native	Perennial
83	<i>Leucopogon</i> sp.4		N	Native	Perennial
84	<i>Davesia</i> sp.4		N	Native	Perennial
85	<i>Platysace</i> sp.1		N	Native	Perennial
86	<i>Hakea</i> sp.1		N	Native	Perennial
87	<i>Acacia pulchella</i>	Prickly Moses	N	Native	Perennial
88	<i>Carpobrotus disphyra</i>	Native Pigface	Ch	Native	Perennial

89	<i>Arctotheca populifolia</i>	Dune Arctotheca	Ch	Exotic	Perennial
90	<i>Acacia harveyi</i>		M	Native	Perennial
91	<i>Unknown sp.8</i>		N	Exotic	Perennial
92	<i>Kennedia prostrata</i>	Running Postman	Ch	Native	Perennial
93	<i>Carduus pycnocephalus</i>		Th	Exotic	Annual
94	<i>Chloris truncata</i>	Windmill Grass	Th	Exotic	Annual
95	<i>Orobanche minor</i>	Lesser Broomrape	G	Exotic	Perennial
96	<i>Lasicpetalum rosmarinifolium</i>		N	Native	Perennial
97	<i>Acacia patagiata</i>		N	Native	Perennial
98	<i>Bossiaea preisii</i>		N	Native	Perennial
99	<i>Conospermum floribundum</i>		N	Native	Perennial
100	<i>Lomandra sp.1</i>		Ch	Native	Perennial
101	<i>Phebalium turbulartum</i>		N	Native	Perennial
102	<i>Phebalium rude</i>		N	Native	Perennial
103	<i>Leucopogon sp.5</i>		Ch	Native	Perennial
104	<i>Unknown sp.9</i>		Ch	Native	Perennial
105	<i>Epacridaceae sp.1</i>		N	Native	Perennial
106	<i>Persoonia teretifolia</i>	Snottygobble	N	Native	Perennial
107	<i>Atroplex sp.1</i>	Saltbush sp.	Ch	Exotic	Perennial
108	<i>Unknown sp.10</i>		Th	Exotic	Annual
109	<i>Arctotheca calendula</i>	Capeweed	Th	Exotic	Annual
110	<i>Grevillea sp.1</i>		N	Native	Perennial
111	<i>Cenopod sp.1</i>		N	Native	Perennial
112	<i>Polygonum arenastrum</i>	Sand Wireweed	Ch	Exotic	Perennial
113	<i>Unknown sp.11</i>		Th	Exotic	Annual
114	<i>Trifolium subterraneum</i>	Clover	Th	Exotic	Annual
115	<i>Unknown sp.12</i>		Ch	Exotic	Perennial
116	<i>Acacia spongellita</i>		M	Native	Perennial
117	<i>Unknown sp.13</i>		Ch	Native	Perennial
118	<i>Hakea laurina</i>	Pincushion Hakea	M	Native	Perennial
119	<i>Hypochaeris radicata</i>	Flatweed	Th	Exotic	Annual
120	<i>Melaleuca elliptica</i>	Granite Bottlebrush	M	Native	Perennial
121	<i>Beaufortia empetrifolia</i>		N	Native	Perennial
122	<i>Unknown sp.14</i>		Ch	Native	Perennial
123	<i>Unknown sp.15</i>		Ch	Native	Perennial
124	<i>Unknown sp.16</i>		N	Native	Perennial
125	<i>Cassytha sp.1</i>	Dodder Vine	P	Native	Perennial
126	<i>Epacridaceae sp.1</i>		N	Native	Perennial
127	<i>Beaufortia micrantha</i>	Little Bottlebrush	Ch	Native	Perennial
128	<i>Pterostylis recurva</i>	Jug Orchid	G	Native	Perennial
129	<i>Leucopogon sp.6</i>		Ch	Native	Perennial
130	<i>Unknown sp.17</i>		N	Native	Perennial
131	<i>Asteraceae sp.2</i>		Th	Exotic	Annual
132	<i>Asteraceae sp.3</i>	Thistle sp.	Th	Exotic	Annual
133	<i>Eucalyptus thamnoides</i> (sub sp. migista)		M	Native	Perennial
134	<i>Hordeum leporinum</i>	Barley Grass	Th	Exotic	Annual
135	<i>Lolium sp.1</i>	Rye Grass	Th	Exotic	Annual
136	<i>Melaleuca sp.9</i>		N	Native	Perennial

137	<i>Haloragodendron glandulosum</i>	Raspwart	N	Native	Perennial
138	<i>Acacia sp.4</i>		N	Native	Perennial
139	<i>Goodia lotifolia</i>		N	Native	Perennial